PHASE ZERO HYPOTHESIS — THE BULL IN THE SKY

Meskhetyu and the Shemsu Hor Path from Nabta Playa to the Giza Plateau

Zep Tepi Series, Bridging the Gap…
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Abstract

> *"Overseer of sculptors, of masons, and of the makers of stone vessels."* — Titles of Imhotep, pedestal of a statue of Djoser, Step Pyramid complex, Saqqara (3rd Dynasty; Cairo JE 49889; Firth, Quibell & Lauer 1935: II, pl. 58; Wildung 1977: 6–8)

The conventional narrative of Egyptian pyramid origins begins with Djoser's Step Pyramid (c. 2670 BCE) and traces an architectural sequence through Sneferu to Giza. That first pyramid was designed by Imhotep, history's first named architect, whose unprecedented translation of mudbrick and reed forms into cut stone established the architectural prototype from which all later pyramids descend. This paper identifies a missing layer: seven small provincial step pyramids built across Upper and Middle Egypt at the late 3rd–4th Dynasty transition. These structures contain no burial chambers, share nearly identical dimensions, and stand at Predynastic ceremonial centres — five of the seven at major ones, two of those carrying explicit Shemsu Hor textual associations. They constitute a Phase Zero of the pyramid tradition — not tombs, but territorial and cultic markers encoding an astronomical inheritance.

The provincial pyramid at el-Kula, near Hierakonpolis, is oriented toward Meskhetyu — the Bull's Foreleg constellation (Ursa Major) — at its circumpolar threshold. The same site has yielded wild bull burials, sheep horn modification, ceremonial adzes matching the Meskhetyu asterism, and carved ivory bulls' legs from the Main Deposit. This convergence of ground-level bull symbolism and celestial bull orientation is consistent with the transmission of Saharan pastoralist astronomical knowledge into the Nile Valley, with antecedents at Nabta Playa, in the Fezzan corridor, and at Gilf Kebir.

The paper proposes that the 500-year gap between the Shemsu Hor period (3800–3100 BCE) and the Great Pyramid (c. 2580 BCE) is not a gap in knowledge but a gap in state capacity. It does not claim to have proven transmission. It identifies Phase Zero as a previously unrecognized architectural program and proposes testable predictions — including aDNA, isotope, and archaeoastronomical surveys — designed to distinguish transmission from independent development.

The Minor Step Pyramids sit at the intersection of archaeoastronomy, paleoclimatology, zooarchaeology, and paleogenomics. The Saharan pastoralist dispersal is documented not only in the Nile Valley but across five sibling branches spanning the Atlantic coast, the Fezzan, the Sahel, the Eastern Desert, and the Lake Turkana basin. Phase Zero offers a testable model for how climatic collapse, cattle pastoralism, and celestial observation combined to produce one of the ancient world's most enduring monumental traditions.

Keywords: Minor Step Pyramids, MSP, Meskhetyu, African Humid Period, AHP, Hierakonpolis HK6, Atbai Enclosure Burials, Takarkori, Nuwayrat, archaeoastronomy, circumpolar orientation, Saharan pastoralism, Early Dynastic Egypt, pyramid origins, Tichitt, Shemsu Hor

Author's Note

This paper was not planned. It emerged while I was trying to bridge the well-known archaeological transition between the late Predynastic Shemsu Hor horizon (c. 3800–3100 BCE) and the sudden appearance of monumental stone pyramid architecture in the 3rd–4th Dynasties. Egyptology has long recognized this roughly 500-year interval as a critical but imperfectly understood period — one in which the ideological and symbolic foundations appear to exist, yet the large-scale expression in cut stone seems to arrive with remarkable speed.

After completing the first three papers—documenting the corridor migration, the genomic evidence, and the institutional memory of the Shemsu Hor—I asked whether the same framework could illuminate the pyramid tradition. It could, and it ran deeper than expected. But something still felt missing.

The Shemsu Hor carried the knowledge. The Great Pyramid expressed it. Between them lay a five-hundred-year silence that the series had not yet explained. I asked a different question: not what was built, but what would it actually take—logistically and technically—to go from Predynastic ceremonial practice to the precision of Giza? What followed was gathering information, calculating, and synthesising every available line of evidence: experimental cutting rates, granite transport logistics, workforce estimates, papyrus records, architectural constraints.

No AI generated this argument. The AIs helped me find, verify, and structure sources. The interpretive framework and editorial judgments are my own.

Series Context
This paper continues the Zep Tepi Series, following:

- **Paper I**: The Eye of the Sahara Hypothesis — identification of the Richat Structure as the surviving candidate origin landscape and documentation of the paleohydrological corridor.
- **Paper II**: Zep Tepi: People of the First Time — genomic continuity from Taforalt through Takarkori to the Nile Valley, the Wedjat sky-compass, and the cattle cult tradition.
- **Paper III**: The Shemsu Hor Hypothesis — the Followers of Horus as the institutional carriers of this knowledge across the transition to the Dynastic period.
- **Supplementaries**: The Sphinx & The Sekhmet — Follows what may have been built and what botanical/medicinal knowledge could have been brought in by Shemsu Hor

This bridging paper sits between Paper III and the next papers. It assumes the evidence established in Papers I–III and does not re-argue those cases. Its contribution is the identification of the Minor Step Pyramids as a previously under-appreciated architectural program—Phase Zero—positioned between Imhotep's prototype at Saqqara and Sneferu's scaled experiments at Dahshur and Meidum, together with the astronomical and spatial evidence that connects that program to the tradition documented in the prior papers.

Released in memory of my mother, Chaya Levy, on what would have been her birthday.

1. Introduction: The Gap Between Memory and Monument

Seven small stone structures in Upper Egypt have been sitting in the archaeological record for over a century. They are not tombs. They contain no burial chambers, no inscriptions, no funerary equipment. They are built at almost identical dimensions from a shared plan, placed at the major Predynastic ceremonial centres — the same sites where the Predynastic ceremonial centres later associated with the Shemsu Hor ('Followers of Horus') tradition are archaeologically documented in bone, ritual deposit, and elite material culture. And at least one of them, el-Kula at Hierakonpolis, is demonstrably oriented toward the circumpolar astronomical tradition that Papers II and III trace from the Saharan pastoral world into the Dynastic record.

These structures were not the first pyramids. That distinction belongs to the Step Pyramid of Djoser at Saqqara, designed by Imhotep — chancellor, high priest, and history's first named architect — approximately one generation earlier. Imhotep's achievement was the conceptual breakthrough: the translation of inherited astronomical and ritual knowledge into monumental cut stone. What he built was a royal tomb and a cosmological statement, the prototype from which the entire pyramid tradition descends.

The Minor Step Pyramids represent something different: the first physical expression of that prototype as a distributed territorial program — Phase Zero — and the evidence that bridges the five-hundred-year gap between the Shemsu Hor and the Great Pyramid.

1.1 Scope of Claims

The argument that follows is structured in three tiers of increasing inferential reach:

Level 1 (Strong): The Minor Step Pyramids constitute a coherent, coordinated program of cultic territorial markers with demonstrable astronomical orientations. This claim rests on directly measured archaeological and archaeoastronomical evidence and does not depend on any transmission hypothesis.

Level 2 (Moderate): The MSPs were placed at sites specifically associated with the Shemsu Hor tradition. This claim rests on the spatial correlation between MSP locations and documented Predynastic ceremonial centers, and is testable by comparing the MSP site list against the full distribution of Predynastic elite sites.

Level 3 (Hypothesis): The astronomical tradition encoded in the MSPs originated with Saharan pastoralist populations and was transmitted to the Nile Valley via the corridor documented in Papers I–III. This claim is inferential, rests on consilience across multiple independent lines.

Distinguishing these tiers is essential. The evidence for Level 1 does not depend on Level 3. Level 3 (transmission) is presented as a hypothesis that depends on the corridor model developed in Papers I–III, which proposes that climatic desiccation of the Green Sahara after 5300 BCE drove a northeast dispersal of pastoralist populations carrying a shared cultural template — cattle ritual, astronomical orientation, and monumental construction — toward the Nile Valley. This paper does not re-argue that case but tests its architectural prediction: that this transmitted knowledge should be detectable in the earliest Egyptian pyramid program. The hypothesis is not independently demonstrated here and is explicitly open to falsification by the predictions in Section 12.

Chronological conventions. Absolute dates in this series follow Shaw (2000) unless stated. For the First Dynasty the series follows the Bayesian radiocarbon chronology of Dee et al.

(2013), which places the foundation of the state (the accession of Aha, 3218–3035 BCE at 95%) earlier than Shaw's historical scheme; this applies to the c. 3100 BCE start of the First Dynasty and Den's accession at c. 2925 BCE used in the papers. For the Naqada phases the papers quote dates from excavation reports (for example HK6, Naqada IC–IIB, c. 3800–3600 BCE); Dee et al. date the Naqada IB/IC transition to about 3650 BCE, IIB/IIC to about 3450 BCE and IID/IIIA to about 3325 BCE, so the earliest of these conventional dates may be up to about 150 years too old. The African Humid Period is taken as c. 14,800–5,500 cal BP; some sources give a start nearer 14,500. Where the series adopts a long Khufu reign (this paper), Fourth Dynasty dates after Khufu move about 26 years later (Khafre c. 2532 BCE; end of the Giza block c. 2477 BCE). Fifth- and Sixth-Dynasty dates, including the Pyramid Texts at c. 2345 BCE, stay on Shaw's scheme, which leaves an overlap of about 17 years at the Fourth/Fifth Dynasty boundary (against Shaw's Userkaf accession of 2494 BCE). The timeline in Section 7 and the construction-time estimates in Section 13 rest on reign lengths and relative order, not on the boundary.

2. The Shemsu Hor: Who They Were and Where They Were

Before examining the provincial pyramids, we must establish the population archaeologically documented at the sites where they were later built.

The Shemsu Hor — the "Followers of Horus" — occupy a non-optional structural slot in Egyptian king-list architecture across fifteen centuries of independent sources: the Turin Royal Canon, the Pyramid Texts, state inscriptions, and temple-building traditions. The Turin Royal Canon lists them as a collective category before the first human kings. Later pharaohs cite their written annals in state inscriptions: the Tombos Stele of Thutmose I records that a feat had never been seen "in the annals of the predecessors since the Followers of Horus" (Sethe, Urk. IV, 82–87). Ptolemaic builders at Dendera cite a leather roll of their time containing architectural plans, recovered from a cavity in the temple's brick wall and recorded as having been found "in ancient drawing, upon a roll of leather of the time of Hor-shesu" (Dümichen 1865; Mariette 1870 –75). Modern Egyptology generally reads such statements as a legitimation topos affirming the antiquity of a temple's design rather than as evidence of a surviving Predynastic document; what the inscription establishes is that the Dendera tradition itself named a specific written archive attributed to the Shemsu Hor. The premise beneath these citations — that the Shemsu Hor refer to a real prepharaonic state of affairs — was granted by Weill on textual grounds alone, decades before any of the corroborating evidence discussed in this paper existed. He treats it as given that the Followers of Horus represent a prepharaonic condition, and confines his scepticism to the narrative of conquest and unification built around them, which he holds could only have been composed after the event (Weill 1961: 198–199). His study was drafted by 1939 and published posthumously in 1961, so it predates the Saharan archaeology, the palaeoclimatic record and the genomic evidence entirely.

Henri Frankfort, in his foundational study *Kingship and the Gods*, identifies the Shemsu Hor with the Souls of Pe and Nekhen — the ancestral figures of the pharaohs who served Horus before unification (Frankfort 1978, Chapter 7; for more recent discussions of Predynastic kingship and ideology, see Baines 1995; Wengrow 2006). Nekhen is the ancient name of Hierakonpolis, the primary site of Predynastic elite activity in Upper Egypt. Pe (later Buto) was the corresponding centre in Lower Egypt, though it was not originally a Horus cult site; it was awarded to Horus through the cosmological settlement of the unification struggle. Whether this tradition encodes the historical memory of a specific Predynastic population, as Papers I–III argue (Levy 2026a, 2026b, 2026c), is an open question. The key point for this paper is geographical: the Shemsu

Hor are anchored to Hierakonpolis, and the archaeological record at that site is summarized below.

The HK6 elite cemetery at Hierakonpolis has yielded multiple lines of evidence consistent with a pastoralist population integrating into the Nile Valley:

- **Sheep horn modification** (Van Neer, De Cupere & Friedman 2024): Tomb 54 at HK6 contained at least six large, castrated male sheep dated to c. 3700 BCE. Four had their horns intentionally modified to grow upward — in three cases resulting in fully upright, parallel horns — while one individual was polled (horns removed entirely). This is the earliest evidence of livestock horn deformation in the world. The practice is not isolated: deliberate cattle horn deformation is documented to the south at Kerma, among the bucrania of the Eastern Cemetery, giving the Hierakonpolis material a comparandum in the direction the corridor model looks.

- **Wild bull (aurochs) burials:** Tomb 19 at HK6 contained the complete skeleton of a wild bull (aurochs), found alone in a large fenced tomb and wrapped in linen and matting (Friedman, Van Neer & Linseele 2011). Tomb 14 contained the skeleton of a juvenile savanna elephant, the earliest known elephant burial in a Predynastic funerary context; a second elephant was later identified in the same cemetery (Van Neer & Linseele 2003), and gut-content analysis of both animals shows they had been fed cereal by-products before death (Marinova et al. 2013) (Adams 1998, *Nekhen News* 10, pp. 3–4).

- **Baboon imports (Van Neer, De Cupere & Friedman 2026):** A 2026 archaeozoological study identified twenty baboon individuals from HK6, buried in the Naqada IC–IIB phase — dated in this series to c. 3800–3600 BCE, on the convention stated above — representing two distinct species — *Papio hamadryas* (native to the Horn of Africa and southern Arabia) and *Papio anubis* (sub-Saharan Africa). Neither species is native to Egypt. The two-species finding is consistent with procurement from more than one source region and constitutes the earliest physical evidence of baboons in Egypt. The authors conclude that the baboons were not routinely bred on site and may have been imported on several occasions, indicating more complex trade interactions with the lands to the far south than previously assumed — contemporaneously with the elephant and aurochs burials.

- **Ceremonial adzes** (Quibell & Green 1900): The Main Deposit at Hierakonpolis yielded ceremonial adzes whose shape matches the Meskhetyu constellation. In later texts, the Meskhetyu asterism is explicitly identified with the adze used in the Opening of the Mouth ceremony.

- **Morphological diversity** (Zakrzewski 2007): craniometric analysis of Predynastic and Early Dynastic samples, including material from Hierakonpolis, demonstrates both overall population continuity and high genetic heterogeneity across the period of state formation. Zakrzewski found significant morphological differences between cemetery-specific temporal groups, indicating that 'some migration occurred along the Egyptian Nile Valley over the periods studied' — a pattern consistent with the integration of external populations alongside indigenous development, though cranial morphology alone cannot identify the specific source region of any incoming group. Zakrzewski's own measurements place the Early Dynastic sample high on the first principal component, with relatively longer and broader cranial vaults and relatively broad faces, so that discriminant analysis separates it from the preceding groups (Zakrzewski 2007: 507). Earlier work had read differences of this kind as evidence for an incoming "Dynastic

Race” (Derry 1956), a reading Zakrzewski’s results explicitly do not support. While the interpretive framework of a distinct 'Dynastic Race' is no longer accepted, the underlying morphological data are consistent with the more recent analyses that inform the present discussion.

- **Dung fuel use and** *Balanites* **offerings** (Marinova et al. 2013; Fahmy, Friedman & Fadl 2008): documented at the site.

The broader significance of this material package for the Saharan transmission argument is developed in Papers I and II (Levy 2026a, 2026b).

At the nearby rural cemetery of Adaïma, contemporary funerary practices included astronomical orientations toward Sirius and the solstices (Alcouffe et al. 2025), indicating that celestial knowledge was not confined to elite centers but was distributed across Upper Egyptian communities in the region of Hierakonpolis during the period of the Shemsu Hor integration.

Whether this population corresponds to the historical 'Shemsu Hor' of later king-lists is an open question. What the HK6 evidence demonstrates is that a pastoralist population with Saharan affinities was present at Hierakonpolis — the site later tradition would identify as the seat of the Followers of Horus. The Shemsu Hor tradition may preserve the institutional memory of this population, but the archaeological and textual categories are not identical, and the distinction matters for the argument that follows.

The cultural horizon from which this pastoralist population emerged has been independently identified in the archaeological literature. Wengrow et al. (2014) have defined a "primary pastoral community" spanning the entire Nile Valley — from Middle Egypt to central Sudan — during the fifth millennium BCE (c. 5000–4000 BCE). This horizon is characterized by shared funerary practices, elaborate body ornamentation, cosmetic palettes, cattle remains in human graves, and a mobile herding-fishing-foraging economy. The authors describe it as representing "a clear cultural break with the Early Holocene past" and the establishment of "a remarkably consistent set of concepts and material practices relating to the treatment of human bodies in life and death" (Wengrow et al. 2014: 95). This cultural horizon predates the HK6 elite cemetery by approximately one millennium, providing the deep temporal context for the pastoralist material package later documented at Hierakonpolis.

The mechanisms by which such a pastoralist population could have achieved elite status within Nile Valley society have been explored by Castillos (2009), who argues that the emergence of hereditary chiefs in Predynastic Upper Egypt was driven by aggrandizing individuals exploiting relaxed social constraints on resource accumulation during the transition from the more mobile Badarian period to the increasingly sedentary Naqada I. Castillos identifies the privatization of storage — archaeologically visible in the shift from communal to household-level granaries at sites including Adaïma — as one material correlate of this process. The elite pastoralist package documented at HK6 is consistent with this model of emergent social stratification. The Shemsu Hor, in this framework, represent the institutional crystallization of a much older pastoralist cultural template — not its inventors, but its carriers into the Dynastic period.

The MSPs were built at this same site approximately 500–700 years later. The connection is spatial and cultural — documented continuity of ritual activity at Hierakonpolis across that interval — not a demonstrated direct builder-to-monument lineage.

The Imhotep Precedent: The First Monumental Translation (c. 2670 BCE)

Before the provincial Minor Step Pyramids and centuries before Giza, one figure gave the inherited cosmological tradition associated with the Shemsu Hor its first durable expression in monumental stone architecture. This was Imhotep, architect and vizier of King Djoser, whose Step Pyramid complex at Saqqara transformed earlier ritual and symbolic traditions into the permanent medium of cut limestone.

Imhotep served under Pharaoh Djoser during the 3rd Dynasty (c. 2670 BCE) and held the influential Heliopolitan priestly title *wr-mɜw* ("Greatest of Seers"), a title conventionally associated with the senior priesthood of Ra at Heliopolis (Helck 1980; Baud 2002: 159–161). The title linked him to the observational and calendrical traditions maintained at Heliopolis. Heliopolis is conventionally described as Egypt's principal solar cult centre, but the priority of the solar element at this date should be qualified. Kahl (2007) has argued from the Thinite epigraphic material that Horus was a star god rather than a celestial god at the beginning of the Early Dynastic period, and that the sun god Ra was introduced only in the Second Dynasty, under Raneb or possibly his predecessor Hetepsekhemwy. Krauss, summarising the position, observes that the reading of the original cosmological ideology of the Egyptian state as stellar — with the king as the earthly embodiment of a planetary body — has entered mainstream Egyptology, and that royal ideology and conceptions of the afterlife appear to have had cosmological and stellar foundations which may well go back to Predynastic times. Notably, the names of five royal vineyards describe Horus as a star, and the name of Djoser's own vineyard identifies him as a particular star at the front of the sky. The office Imhotep held therefore sits at a moment when Heliopolitan observation was not yet solar in the sense it later became. His historical role in the Step Pyramid project is securely attested by inscriptions on a statue base from the complex. Wildung, whose study remains the standard treatment, reads five status titles before the name and three craft titles after it. Two of the five carry works-direction sense in themselves: sḏ3wtj bjtj, "sealer of the King of Lower Egypt", encompasses the functions of the Bauleiter, and ḥk3 ḥw.t-ʿ3.t is an honorary title of Bauleitern. The three craft titles — rendered by Wildung as overseer of the bone-carvers, of the worker with the spatula, and of the maker of stone vessels, and in general sense as chief of works, leader of the masons and leader of the makers of stone vessels — together describe, on his reading, the essential craft activities of a large building project: the working of wood, Nile mud and stone into architecture, sculpture and vessels. Wildung concludes that the appearance of Imhotep's name on the base of a statue of his royal master identifies him as planner and builder of the tomb complex, and that this is the first expression of Imhotep as Baumeister, master builder (Firth, Quibell & Lauer 1935: II, pl. 58; Wildung 1977: 6–8). The stone-vessel title carries particular significance in the context of this series. Paper I (Levy 2026a) proposes testing hard-stone vessels whose quarries remain unknown against the Richat's distinctive tri-lithic suite as a marker of corridor-derived expertise; the Predynastic basalt vessels, by contrast, have been traced to the Haddadin flow near Cairo (Mallory 2000). The architect of the first pyramid simultaneously held mastery over this lineage. Whether the convergence of cosmological architecture and corridor-associated craft expertise in a single figure reflects a direct institutional connection remains open; what it is not is coincidental. The inclusion of a non-royal name on a royal monument was itself an exceptional mark of status in the Old Kingdom, indicating that Imhotep's prominence was recognized in his own lifetime, not merely projected backward by later tradition. More than two millennia later, Manetho's epitome records under the Third Dynasty that Tosorthros, reigning twenty-nine years, was reputed among the Egyptians an Asclepius for his medical skill and was the inventor of the art of building with hewn stone (Waddell 1940: 41–43). Waddell's text attributes these achievements to Imhotep through the supplement "in his reign lived Imuthes", which he prints within angle brackets to mark it as a modern editorial restoration rather than transmitted text.

Wildung, whose study of Imhotep's deification this paper draws on elsewhere, rejects that emendation as unprovable and unnecessary, and the Eusebian recension attaches the Asclepius identification to the king rather than to his official. Manetho's text as transmitted therefore names Tosorthros, and the association with Imhotep is a later scholarly inference. The point is worth stating plainly because the argument advanced here does not depend on it: what is attested contemporaneously are the titles, and it is the convergence of craft authority and cosmological office in a single individual, not the later tradition of his inventions, that carries the argument.

What emerged at Saqqara was unprecedented in both scale and conception. Rising approximately 62.5 metres in height, the Step Pyramid was the earliest colossal structure constructed entirely in cut stone and marks a decisive turning point in the history of world architecture (Lehner 1997: 84–87; Arnold 2003: 43–48). Excavations and architectural analysis by Jean-Philippe Lauer, who worked at Saqqara for more than seventy years beginning in 1926, demonstrated that the monument evolved through multiple construction phases rather than following a single fixed design. The structure began as a square mastaba before successive enlargements and superimposed stages transformed it into the final six-tier pyramid (Lauer 1936; Lauer 1962). This developmental sequence reveals a process of experimentation and architectural adaptation rather than the execution of a static inherited formula. The Step Pyramid complex therefore represents not merely technical innovation, but the monumentalization of an already mature symbolic and ritual system into a new architectural medium.

The surrounding complex covered approximately 15 hectares and was enclosed within a massive limestone temenos wall over 10 metres high, articulated with bastions and recessed palace-façade panelling derived from earlier mudbrick royal enclosures (Arnold 2003: 49–53; Lehner 1997: 85–86). Within this precinct, architectural forms previously executed in perishable materials—including reed structures, timber columns, woven mat façades, and mudbrick elements—were translated into permanent limestone equivalents. In doing so, the complex established much of the formal vocabulary that would characterize later Egyptian monumental architecture (Arnold 2003: 50–51; Wilkinson 2000: 113–119). The complex incorporated ceremonial spaces including the Heb-Sed court, the North and South Houses, the serdab chamber, and an extensive subterranean network of galleries and chambers extending several kilometres beneath the pyramid itself (Lehner 1997: 86–88; Dodson & Ikram 2008: 31–38).

Particularly significant for the present argument is the complex's explicit northern celestial orientation. On the pyramid's north side, a sealed serdab chamber housed a seated statue of Djoser. Two small apertures cut through the wall at eye level permitted the statue to gaze toward the northern sky, and their targets have been reconstructed: the two sightlines, at inclinations of roughly 12° and 20° along the complex's axis, correspond to Dubhe in Ursa Major — that is, within Meskhetyu itself — and to Kochab in Ursa Minor at around 2600 BCE (Shaltout, Belmonte & Fekri 2007: 413–14; Magli 2018: 50). The burial chamber was decorated with rows of five-pointed stars in low relief, and the entrance passage, seen from within, forms a ramp directed northward toward the circumpolar region (Firth, Quibell & Lauer 1935: 69–70; Lehner 1997: 87). In Egyptian royal funerary ideology, the northern circumpolar stars—the *ikhemu-sek*, or "Imperishable Ones"—were associated with eternal cyclical continuity because they never disappeared below the horizon. Among the most important associated constellational forms was Meskhetyu, conventionally identified with the Bull's Foreleg and linked with the seven bright stars of Ursa Major (Belmonte & Lull 2023: 250–253; Krauss 1997: 120–121). The Pyramid Texts place it explicitly among the imperishable ones at Pyr. §458a–c, and its observational use is documented: Krauss notes that the angular positions of Meskhetyu were taken at fixed points in the night — at its beginning, at its middle, and finally at hd-t3, the

moment when the stars of the Plough vanish at the onset of civil dawn, corresponding to the sun standing some seven degrees below the horizon. The constellation was thus a working instrument of nocturnal timekeeping as well as a funerary symbol, and the identification with Ursa Major is corroborated late in the tradition by the round zodiac at Dendera, where the foreleg is set beside Gemini, Cancer and Leo, which is approximately where Ursa Major stands in the sky (Priskin 2019: 160, 179). Priskin notes further that Meskhetyu was probably the single most important constellation for the Egyptians, on the grounds that it was the feature of the sky observed during temple foundation rituals to determine the cardinal directions (Priskin 2019: 140, citing Kurth, Edfou VII: 75–76) — a role that bears directly on the argument advanced here. The serdab orientation provides direct architectural evidence that circumpolar stellar symbolism had already been materially encoded into royal pyramid architecture at the very inception of the pyramid tradition.

Imhotep's significance extended far beyond the Old Kingdom. During the Late Period (c. 664–332 BCE), he was deified as a god associated with wisdom, healing, scribal knowledge, and medicine, with an active cult centred at Saqqara near the Step Pyramid itself (Wildung 1977: 34–42; Teeter 2011: 108). Greek writers later identified him with Asclepius, their own god of healing (Omran 2014: 69; see also Sethe 1902). New Kingdom scribes invoked his name and poured water libations in his honour before commencing literary work, reflecting his enduring status as patron of learned knowledge and intellectual practice (Gardiner 1938: 163; Wildung 1977: 27). In Late Period iconography he frequently appears seated as a scribe holding an unrolled papyrus across his lap, visually reinforcing his association with preserved and transmitted knowledge (Wildung 1977: 95–97; Wilkinson 2003: 106).

The Step Pyramid complex appears to form an important architectural and ideological bridge between earlier ritual traditions and the later territorial symbolism of the Minor Step Pyramids. Imhotep's achievement was not simply technological. The Saqqara complex embedded cosmological principles—northern stellar orientation, royal ascension symbolism, sacred enclosure, and the translation of ephemeral ritual forms into permanent stone—within a monumental architectural program whose influence would define Egyptian state expression for centuries. In this sense, the Step Pyramid may represent the first large-scale state monumentalization of ideological traditions whose deeper antecedents can be traced to Predynastic pastoral and ceremonial cultures, including those documented at Nabta Playa (see Levy 2026a, 2026b).

At the same time, caution is required. The connection between the Step Pyramid complex and the later Minor Step Pyramid network remains interpretive rather than directly documented. No surviving inscription explicitly links Imhotep, Djoser, or the Step Pyramid project to the Shemsu Hor tradition or to the construction of the provincial pyramids. Nevertheless, the continuities in symbolic grammar—notably stepped form, northern celestial orientation, and the encoding of cosmological order into enduring architecture—strongly suggest that the Minor Step Pyramids emerged within an ideological framework already established at Saqqara.

Imhotep did not build the Minor Step Pyramids. But the architectural and cosmological template established at Saqqara made their later development conceivable. Whether Imhotep descended from the Saharan corridor populations documented in Papers I–III is a question the current evidence cannot answer: his tomb has never been located, and no identified remains exist. What his institutional position does suggest is a structural observation. The wr-mꜣw title placed him at the apex of Egypt’s principal astronomical observatory. The ‘Chief of Makers of Stone Vessels’ role placed him at the head of the craft tradition Paper I proposes to test against the Richat geology. His non-royal prominence derived entirely from specialised knowledge. Taken together, these suggest that Imhotep may represent the institutional crystallisation point of the

Shemsu Hor transmission — not a first-generation carrier, but the figure at whom centuries of preserved knowledge, maintained in priestly lineages at Heliopolis and Memphis, finally found the capacity for monumental expression. Should his tomb be located and yield recoverable material, it would constitute one of the most diagnostic aDNA tests the series could propose.

3. Phase Zero: The Seven Provincial Minor Step Pyramids

The seven minor step pyramids of Upper Egypt are the physical core of this paper's argument. This section documents what they are, when they were built, who built them, and where they were placed — establishing the archaeological baseline before the astronomical and institutional arguments that follow. The evidence presented here is mainstream, peer-reviewed, and does not depend on this paper's hypothesis to stand.

Identification as a Coherent Group

Dreyer and Kaiser (1980) first identified the seven minor step pyramids as a coherent architectural group, documenting their nearly identical base dimensions (approximately 18.4 m, or 35 cubits), three-step construction, and — critically — the complete absence of internal chambers or substructures. For an accessible summary of their findings, see Lehner (1997, p. 96).

Belmonte, Shaltout and Fekri (2005: 7) confirm the defining characteristics: stones of approximately 60 × 100 cm, a square base of approximately 35 royal cubits (~18.4 m), three steps in most cases, and — critically — "the absence of any associated chamber that could help to identify them as tombs or cenotaphs." In their 2023 synthesis, Belmonte and Lull reaffirm that the MSPs constitute a coherent program whose analysis proved "extremely fruitful," demonstrating that "a combination of land- and skyscape could help easily to explain their purpose, location and orientation" (Belmonte & Lull 2023, p. 389).

Six of the seven share almost identical base dimensions (18.30–18.60 m), indicating construction from a single shared plan. El-Kula, near Hierakonpolis, is the best preserved of the group. Sinki, near Abydos, was found with its mud-brick construction ramps still in situ, unfinished at the second step (Belmonte et al. 2005: 7).

Attribution and Date

Attribution oscillates between Huni, last king of the 3rd Dynasty, and Sneferu, first king of the 4th Dynasty. Dreyer and Kaiser (1980) attributed the group to Huni on the basis of a stone cone bearing his name, found in a Third Dynasty administrative building at Elephantine. The evidence is slight and has been questioned: Belmonte and colleagues describe Elephantine as assigned to Huni on tiny evidence, and Ćwiek has argued that the cone may have been reused in Ramesside restoration work at Old Kingdom cult places, in which case it dates the restoration rather than the pyramid. Seila remains the only minor step pyramid securely attributed to a named king. A stela at Seila confirms Sneferu's involvement with that pyramid specifically (Belmonte et al. 2005, p. 1). Ćwiek (1998) argued for Sneferu as the builder of all seven, interpreting them as royal cult sanctuaries established early in his reign and abandoned once resources were concentrated on the large pyramids.

For the purposes of the transmission argument, the attribution matters less than the timing: the MSP program brackets the 3rd–4th Dynasty transition, placing the first appearance of the pyramid form as a territorial marker immediately after the Shemsu Hor institutional period. For the capacity-scaling argument, however, the Sneferu attribution is actually the stronger position.

If the MSPs are Sneferu's work — as Ćwiek argues and as the Seila stela directly confirms for at least one of them — then Phase Zero and the R&D phase described in Section 8 form a continuous program under a single dynasty: the same king built the distributed provincial markers and then, having demonstrated mastery of the step-pyramid form at small scale, scaled it aggressively to burial-pyramid size at Dahshur and Meidum. The story becomes a coherent single-dynasty arc of accelerating ambition rather than a dynasty inheriting an earlier program it did not begin.

The MSP date range of c. 2613–2590 BCE used throughout this paper assumes the Sneferu attribution; if the Huni attribution is correct, the date range shifts earlier by approximately one generation. The argument does not depend on the precise dating. The MSP program thus coincides with a period of documented ritual transformation across Upper Egypt. At Adaïma, near Hierakonpolis, Alcouffe et al. (2025) have shown that the Third Dynasty marked the peak of funerary innovation and the consolidation of new ritual forms — the same window in which the pyramid form was first deployed as a territorial-cultic marker at provincial centers.

Location: The Shemsu Hor Sites

Belmonte et al. (2005, p. 2) document what is, from this hypothesis's perspective, the most important fact about the MSPs: "MSPs were located at or nearby the location of some of the most important capitals of the ancient provinces of Upper Egypt during the Old Kingdom: Abu (Elephantine), Behedet (Edfu), Nekhen (el-Kula), Nubt (Naqada) and This-Abydos (Sinki)."

These are not arbitrary provincial towns. Elephantine, Hierakonpolis, Naqada, and Abydos were the four dominant ceremonial centres of Predynastic Upper Egypt. Hierakonpolis and Abydos are explicitly associated with the Shemsu Hor in later texts; Elephantine, Edfu, and Naqada were major Predynastic centres whose Old Kingdom importance made them natural nodes for state integration. The administrative significance of these sites is further indicated by the titulary of Old Kingdom officials associated with them. Fischer (1996) has analyzed the title *r- Nḫn* ('Mouth of Nekhen'), connecting it to judicial and state functions centered on Hierakonpolis — the same site where the el-Kula MSP was erected. The persistence of such titles into the Old Kingdom indicates that the administrative identity of these Predynastic centers was not merely remembered but remained institutionally active during the period of the MSP program. The spatial correlation of all seven MSPs with Predynastic ceremonial centers — regardless of the strength of textual attestation at each individual site — is the core observation.

Table 1: MSP Locations, Predynastic Status, and Shemsu Hor Textual Associations

MSP Site (Pyramid)	Ancient Name	MSP Present	Predynastic Ceremonial Activity	Shemsu Hor Textual Association	Old Kingdom Provincial Capital Rank
Elephantine	Abu	Yes	Documented (Predynastic settlement; early temple)	Inferred (major Predynastic centre)	High (nome capital)
El	Behedet	Yes	Documented	Inferred (major	High (nome

MSP Site (Pyramid)	Ancient Name	MSP Present	Predynastic Ceremonial Activity	Shemsu Hor Textual Association	Old Kingdom Provincial Capital Rank
Ghoneimiya (South Edfu)			(Predynastic cemetery; Naqada-period occupation)	Predynastic centre)	capital)
El-Kula	Nekhen (Hierakonpolis)	Yes	Documented (HK6 elite cemetery; HK29A ceremonial centre; Tomb 100)	Explicit (Frankfort 1978, Chapter 7; Turin Canon; Pyramid Texts)	High (nome capital)
Naqada	Nubt	Yes	Documented (type site for Naqada culture; extensive Predynastic cemeteries)	Inferred (major Predynastic centre)	High (nome capital)
Sinki (near Abydos)	This-Abydos	Yes	Documented (royal necropolis; Predynastic cemeteries)	Explicit (burial place of early kings; Shemsu Hor king-list associations)	High (nome capital)
Zawiyet el-Mayitin	—	Yes	Inferred (provincial centre; limited Predynastic excavation)	Inferred	Medium
Seila	—	Yes	Inferred (located near Predynastic settlement patterns)	Inferred	Medium

Sources: Belmonte et al. (2005) for MSP locations; Dreyer & Kaiser (1980) for identification; Friedman (2009) for Hierakonpolis; Bussmann (2014, 2023) for provincial capital status. Shemsu Hor associations follow Frankfort (1978) and the Turin Canon.

Of the seven MSP sites, two have explicit Shemsu Hor textual associations (Hierakonpolis and

Abydos), four are among the dominant Predynastic ceremonial centres of Upper Egypt (Elephantine, Hierakonpolis, Naqada, Abydos), and all seven correspond to Old Kingdom nome capitals or major provincial centres in current syntheses. The state-integration model predicts MSPs at provincial capitals regardless of Predynastic history, and it has a published proponent whose case must be met rather than assumed away. Bárta (2005: 181) surveys the same seven monuments and concludes that “in all cases they were located in the vicinity of the major settlements and power centres of the ancient Egyptian state”, reads them as “indicators of major royal economic centres”, and observes that their distribution is almost identical to that of the major irrigation basins on which Egyptian agriculture depended. He also notes that most stand at higher elevations giving unobstructed visibility despite their low height. That is a positive mechanism, not a null hypothesis, and on the present evidence it accounts for the siting as economically as the transmission model does. The transmission model predicts clustering at sites with Predynastic ceremonial significance and especially at those with documented Shemsu Hor associations.

To evaluate these competing predictions, the distribution of the seven MSPs was tested quantitatively against the approximately 22 Upper Egyptian Old Kingdom nome capitals (following Helck 1974; Baines & Málek 2000; Bussmann 2014). A site was classified as having "strong association" if it possessed both (a) documented major Predynastic ceremonial activity (elite cemeteries, temple foundations, or major ritual deposits predating 3100 BCE) and (b) explicit or strong textual association with the Horus cult or Shemsu Hor tradition in later sources (Pyramid Texts, Turin Canon, or state inscriptions; see Paper III, Appendix A). Five of the seven MSP sites meet both criteria: Elephantine, Edfu, Hierakonpolis, Naqada, and Abydos. Two further nome capitals meet both criteria without possessing an MSP, and are recorded as such in Table 2. The two models are not mutually exclusive: Predynastic ceremonial centres and Old Kingdom economic centres overlap heavily, since both follow the same productive stretches of floodplain. What discriminates between them is the residual — whether MSPs appear at economically major sites that lack Predynastic ceremonial activity, and whether they are absent from Predynastic ceremonial centres of limited Old Kingdom economic weight. Bárta’s irrigation-basin correspondence makes that residual the decisive test rather than a refinement of it, and Prediction 6 is framed accordingly. Classification was based on published excavation reports and standard syntheses (Helck 1974; Wilkinson 1999; Bussmann 2014, 2023; Frankfort 1978).

Table 2: Contingency Table for MSP Distribution by Site Association (22 Upper Egyptian nome capitals, following Helck 1974; Baines & Málek 2000)

	Strong Association	Other Sites	Total
MSP present	5	2	7
MSP absent	2	13	15
Total	7	15	22

A Fisher's exact test on this table yields p = 0.0136 (odds ratio = 16.25). Given the small sample size (7 MSP sites among approximately 22 Upper Egyptian nome capitals), Fisher's exact test was selected rather than chi-square because it remains reliable under low expected cell counts. The probability that this degree of clustering would occur by chance under a null model of random administrative placement is approximately 1.36%. The result depends on how "strong

association" is defined; the classification adopted here is stated above so that alternative schemes can be tested against it. While the result does not by itself demonstrate intentionality or transmission, it indicates that MSP placement is unlikely to reflect administrative distribution alone and is more consistent with preferential selection of Predynastic ceremonial centres associated with the Shemsu Hor tradition. These findings provide quantitative support for Level 2 of the hypothesis.

Function: Cultic, Not Funerary

Marouard (Oriental Institute, University of Chicago, 2014) excavated the provincial pyramid at Edfu and found food offering installations on the pyramid's eastern side. The pyramid was abandoned — offerings ceased — during the reign of Khufu, less than 50 years after construction. Marouard's interpretation is direct: Khufu "no longer thought there was a need to maintain a small pyramid at Edfu, or elsewhere in southern Egypt" because he was concentrating all resources at Giza.

Ćwiek's interpretation, endorsed by Belmonte, is consistent: the MSPs were "local sanctuaries built under Sneferu for the royal cult" (Belmonte et al. 2005, p. 2). The pyramid form arrived at Hierakonpolis not as a tomb but as a territorial and cosmological marker — and it arrived at the site of the Shemsu Hor's own integration before any king was buried in a pyramid.

The characterisation of the MSP program as a coordinated state effort is not unique to this paper. Richard Bussmann, Professor of Egyptology at the University of Cologne and co-director of ongoing excavations at Zawyet Sultan — one of the seven MSP sites — characterises these provincial pyramids as instruments of state integration: symbols of royal authority built at provincial sites as part of a deliberate effort by the crown to extend its control across the hinterland of Upper Egypt (Bussmann 2014; 2023, Chapter 10). The seven MSPs share identical dimensions, the same construction method, and systematic placement at provincial capitals.

Bussmann (2014, 2023) interprets the MSP program as an instrument of state integration — the crown extending its symbolic authority across Upper Egypt. This interpretation is consistent with the evidence and does not conflict with the present hypothesis. However, the state-integration model does not predict the specific site selection: it would expect MSPs at any significant provincial capital, regardless of that site's relationship to the Shemsu Hor tradition. The present hypothesis makes a further, testable prediction: if the MSPs encode institutional memory of the Shemsu Hor integration sites, they should cluster at those specific locations, not merely at important provincial centers. Testing this prediction requires comparing the MSP site list against the full distribution of Predynastic ceremonial centers. If all seven MSPs map to Shemsu Hor-documented sites (Hierakonpolis, Elephantine, Edfu, Naqada, Abydos), the clustering is not explained by state integration alone. This distinguishes the two models and provides a falsifiable criterion for future research — one that depends purely on spatial archaeology rather than astronomical or symbolic inference.

Several functions have been proposed for the group. Belmonte and colleagues list cenotaphs for the ka or for queens in their homelands, archaic benbens standing as forerunners of the Fifth Dynasty solar temples, and local symbols of royal power at important provincial cities; Ćwiek's royal-cult sanctuaries belong to the last of these. The benben reading deserves particular note here, since it is itself a cosmological interpretation and would locate the monuments within solar rather than stellar symbolism. The cenotaph interpretation — that the MSPs served as symbolic tombs for queens — is weakened by the installation identified against the eastern face at Edfu, where a diagnostic trench exposed the negative of a dismantled structure in the position that

becomes standard for funerary chapels under Sneferu. A cenotaph, as a symbolic tomb, would not require an installation of this kind; the excavation report notes, however, that no standing remains of installations survive along the pyramid's sides (Marouard 2014). The nearly identical base dimensions of six of the seven MSPs (18.30–18.60 m) are consistent with construction from a single shared plan for a unified program (Dreyer & Kaiser 1980; Belmonte et al. 2005), though this alone does not discriminate between territorial markers and cenotaphs — a unified royal program could produce identical cenotaphs.
The cultic evidence provides the stronger discriminating test, and together the two lines of evidence point toward a coordinated territorial marking program rather than individual symbolic burials.

Architectural Precursors: The Subterranean Tumuli at Umm el-Qa'ab

Engel (2008, pp. 35–36) documents mud-brick subterranean tumuli inserted between the royal burial chamber ceiling and the desert surface in 1st Dynasty tombs at Umm el-Qa'ab (Aha, 'Snake', Den, and Qa'a). She states:

> "Shape and location above the royal burial indicate that they were precursors of later pyramids — the first building phases of the step pyramid in the burial complex of Netjerikhet still show the steep angle which was observed for the subterranean tumuli. Therefore it seems possible to attribute similar symbolic meaning to them as to the pyramids, i.e. as an image of the primeval hill and/or as an aid for the dead king to ascend to heaven."

This establishes the architectural lineage within which the MSPs must be understood. At Umm el-Qa'ab, the primeval-mound symbolism was tied to the personal resurrection of the deceased king — the tumulus sat directly above the burial. The MSPs detached the mound form from the burial chamber entirely. They were not cenotaphs in the sense of substitute tombs for specific individuals, but state mounds: the same cosmological grammar applied to a different function.
The same architectural progression is visible in the Predynastic cemeteries of Upper Egypt, where Randall-Maciver and Mace (1902) traced the evolution of tomb forms from simple round graves through recessed rock-cut chambers to multi-chamber brick tombs — a sequence that parallels the broader trajectory from subterranean tumulus to above-ground monumental enclosure. Where the Umm el-Qa'ab tumuli aided a king's ascent, the MSPs marked the crown's territorial authority at provincial centers that had been the integration sites of the Shemsu Hor tradition. The Edfu offering installations confirm active cultic use, consistent with a territorial marker receiving ongoing ritual attention.

The 'Phase Zero' designation refers to the MSPs as the first provincial expression of this tradition — not a separate architectural lineage, but the same symbolic vocabulary expanded outward from the royal center. The subterranean tumuli at Abydos (Dynasty 1) were funerary and personal; the Step Pyramid at Saqqara (Djoser, Dynasty 3) externalized the form above ground at the royal center; the MSPs (late Dynasty 3/early Dynasty 4) distributed it across Upper Egypt as a network of territorial markers. This is a single tradition expanding spatially and functionally, not two parallel traditions converging.

Environmental conditions reinforced this architectural shift: multiple lines of evidence indicate wetter climatic conditions during the Early Dynastic period and Old Kingdom, which would have reduced mudbrick durability and actively facilitated the adoption of stone as the medium for monumental construction (Wong 2021).

Lithological evidence from the quarry west of the Step Pyramid indicates cyclical watering and intensive evaporation during Djoser's reign, raising the possibility that the great trench

surrounding the complex (the 'dry moat') held water following downpours (Welc 2011; Trzciński et al. 2010, cited in Wong 2021). This requires caution: the humid phase documented in the Saqqara geoarchaeological record is dated to the late Old Kingdom and early First Intermediate Period, some four centuries after Djoser, and cannot be assumed to describe conditions at the time of construction. If correct, this would mean that the primeval mound of the Step Pyramid was visually surrounded by water during the wet season — the Nun cosmology made physically manifest at the very inception of monumental stone architecture, and a direct precursor to the water integration achieved at Giza through the Khufu Branch canal.

4. El-Kula at Nekhen: The Hierakonpolis Connection

El-Kula is located approximately 6 km north of the ancient site of Hierakonpolis near the village of Naga el-Mamariya (confirmed by Belmonte et al. 2005). In the ancient provincial system, el-Kula is the pyramid for Nekhen — the Predynastic name of Hierakonpolis.

The HK6 elite cemetery at Hierakonpolis, whose full pastoralist material package is detailed in Section 2, has yielded wild bull (aurochs) burials in Tomb 19 (Friedman, Van Neer & Linseele 2011, *Egypt at its Origins 3*, pp. 157–191), sheep horn modification, ceremonial adzes matching the Meskhetyu asterism. Zakrzewski's (2007) craniometric series bears on the population history of the period rather than on this cemetery: her Hierakonpolis material is thirty-seven crania in the Duckworth Collection assigned to the Late Predynastic, and the heterogeneity she documents is in the Early Dynastic sample from Abydos El-Amrah (Zakrzewski 2007: 504, 507). Cranial morphology cannot identify a source region, and no such identification is claimed here.

The provincial pyramid at el-Kula appears at this same site within 500–700 years of that integration, built in stone with no burial chamber, oriented according to an astronomical logic that, as the next section demonstrates, aligns with the same bull/cattle tradition in celestial form.

The spatial relationship between HK6 and el-Kula is set within a documented context of continuous cultic activity at the site. The ceremonial center at HK29A in the low desert at Hierakonpolis was in continuous use from Naqada IIA through Dynasty 1 — approximately 500 years, directly overlapping the HK6 elite cemetery period (Friedman 2009, JARCE 45: 79–104; Droux, Friedman & Pieri 2024). The last king of the 2nd Dynasty, Khasekhemwy (c. 2690 BCE), built a monumental mud-brick enclosure at Hierakonpolis. Kemp places its niched gatehouse in the same Early Dynastic royal idiom as the Shunet el-Zebib, Khasekhemwy's enclosure at Abydos, and reads the Step Pyramid complex — a generation later — as still preserving the basic shape of that Abydos enclosure (Kemp 2018: 102, 104). El-Kula was not built at an abandoned site. It was built at a place with deep and periodically renewed ritual significance — the Khasekhemwy enclosure (c. 2690 BCE) marks continuing royal interest at the site in the interval between the HK29A ceremonial center and the MSP construction.

The regional context reinforces this continuity. At the nearby rural cemetery of Adaïma, material connections to Hierakonpolis are documented by prestige goods — including an ivory boat model matching those from the Hierakonpolis Main Deposit — and by funerary orientations toward Sirius and the solstices that parallel the astronomical concerns later encoded at el-Kula (Alcouffe et al. 2025). The spatial relationship between HK6 and el-Kula was not an isolated phenomenon; it was embedded in a broader Upper Egyptian landscape of communities sharing material culture and celestial knowledge centered on Hierakonpolis.

Auger surveys at Hierakonpolis indicate a relatively humid interval during this period, with rainwashed sediment from the Wadi Abul Suffian dated to c. 5200–4500 BP (Hoffman et al. 1987, cited in Wong 2021). This humid interval predates MSP construction; for Old Kingdom

humidity evidence contemporary with the MSPs, see Wong (2021). The site's early temple — a low artificial mound of sand held in place by a revetment of small roughly cut sandstone blocks (Quibell & Green 1902), which later work measures at 48 × 48 m and 2.3 m high (Kemp 2018: 129) — would have provided protection against wadi wash events during episodes of heavy rainfall. Simultaneously, the revetment would have created an image of the primeval mound emerging from the pre-creation waters, a visual conflation of practical necessity and cosmological symbolism that prefigures the later integration of water and stone at the Step Pyramid complex and at Giza. The temple identification should be stated as an interpretation rather than a fact. McNamara (2008) has argued that the archaeological remains offer little support for it, noting that any structures which stood on the mound were obliterated by the foundations of the later temple, and proposing instead that the enclosure was a royal ritual precinct, an arena for ceremonies associated with kingship, reconstructed by analogy with the scenes on the Narmer mace-head. Kemp, who records McNamara's re-interpretation, himself leans the other way, reading the central brick building as the shrine itself, with the copper image of Horus in one chamber and royal statues in another (Kemp 2018: 129). The arena he describes for Djoser's complex — "the great enclosed arena or plaza of the royal appearance", with its paired cairns and stepped platform shown in use on the Narmer mace-head for reviewing captured livestock and prisoners — is the model on which such a reading rests (Kemp 2018: 102, 105). On this reading the Main Deposit is not a cache of votive material offered to a deity but an assemblage more intelligible in relation to royal cultic activity and ideology. That reading no longer rests on McNamara alone. Bussmann's comparative survey of early temple votives finds that objects carrying royal or king-centred iconography occur at Hierakonpolis and nowhere else, that ivory votives of that kind are "largely confined to Hierakonpolis, revealing the exceptional role that this temple played at the beginning of Dynastic history", and that the site "is a clear exception during the period of state formation and cannot serve as a model for other temples" (Bussmann 2011: 756–7, 760). His wider finding is that provincial temples of the third millennium sat in a local milieu "characterised by loose contact with the court and king" and were transformed from local into royal institutions over the course of that millennium (Bussmann 2011: 760) — the process into which the present paper places the minor step pyramids. That reinterpretation does not weaken the argument advanced here; if anything it sharpens it. The ceremonial adzes and the ivory bulls' legs discussed in Section 6 become royal ritual equipment rather than generic temple offerings, and the convergence this paper traces between kingship, cattle symbolism and the northern sky is precisely what a royal ceremonial precinct at Nekhen would be expected to express. The primeval-mound reading, Kemp's shrine reading and McNamara's royal-precinct reading are not mutually exclusive, but the paper follows the second in treating the Main Deposit objects as royal rather than devotional in character.

The spatial relationship is not the argument. The spatial relationship is the starting point. The argument is that the astronomy confirms the cultural connection.

5. The Astronomical Evidence: Meskhetyu and the Bull in the Sky

The architectural evidence establishes that the MSPs were built at Predynastic integration sites. The astronomical evidence establishes what they were oriented toward. This section presents Juan Antonio Belmonte's archaeoastronomical field measurements of all seven pyramids and traces the chain from those measurements to the circumpolar tradition documented at Nabta Playa, through HK6 at Hierakonpolis, to the pyramid-building era. The el-Kula result is the linchpin: it connects the two datasets.

Belmonte's Field Measurements

Belmonte, Shaltout & Fekri (2005) conducted systematic archaeoastronomical measurements of all seven MSPs using high-precision compasses corrected for local magnetic declination, achieving an estimated error of approximately ½° in both azimuth and angular height. Their complete orientation data are reproduced in Table 3 below. A second team has since revisited the same question independently (see also Ali, Fekri & EL Mahdy 2021); that study has not been consulted in full here, and nothing in the present argument rests on it.

Table 3: Orientation data for the seven Minor Step Pyramids of Egypt (after Belmonte, Shaltout & Fekri 2005, Table 1). El-Kula highlighted.

Pyramid	Latitude	Azimuth (N face)	Horizon declination δ (°)	Astronomical Interpretation
Elephantine	24°06'N	343°	60½° (N face); 16¼° (second axis, a*=73°, h*=2°)	Sunrise at Wepet Renpet (Egyptian New Year) c. 2570 BCE (Belmonte et al. 2005)
El Ghoneimiya (South Edfu)	24°56'N	3.5°	66½° (N face, a=3½°, h=2°)	Lower culmination of Merak (β UMa) at horizon c. 2570 BCE — first point where Meskhetyu ceases to be circumpolar
el-Kula (Hierakonpolis)	**25°08'N**	**316.25°** (quarter-cardinal)	**40½° (N face); 66¾° (second axis, a*=1¼°, h*=2°)** (primary), **66.75°** (secondary)	Quarter-cardinal orientation, same Meskhetyu family as El Ghoneimiya. Secondary axis δ* = 66.75° at h* = 2°, pointing to circumpolar Meskhetyu. Site = Nekhen, 6 km from HK6.
Naqada	25°58'N	24.5°	55° (N face); −22¼° / −21° (second axis, a*=114½°)	Heliacal rising of Sirius (Sopdet) c. 2500 BCE
Sinki (near Abydos)	26°09'N	318.75°	42° (N face); 63° (second axis, a*=3¾°)	Quarter-cardinal family; similar orientation to el-Kula. Left unfinished.
Zawiyet el-Mayitin	28°03'N	331.75°	50½° (N face); −24¾°	Winter solstice sunset; last point in Egypt where Polaris (α UMi)

Pyramid	Latitude	Azimuth (N face)	Horizon declination δ (°)	Astronomical Interpretation
			(second axis, a*=241¾°)	was circumpolar c. 2570 BCE
Seila	29°23'N	0° (true north)	60° (N face, a=0°, cardinal)	First pyramid ever cardinally oriented; simultaneous meridian transit of Phecda and Megrez (γ and δ UMa) c. 2570 BCE

A note on the Seila orientation. The cardinal orientation attributed to Seila here follows Belmonte, Shaltout and Fekri (2005) and is not universally reported. Several standard reference descriptions instead place Seila some twelve degrees west of north and group it with Elephantine, Naqada and Zawiyet el-Mayitin as oriented parallel to the Nile. That figure derives from Dreyer and Kaiser and is repeated by Lehner, but it has been superseded rather than merely disputed. Belmonte and colleagues remeasured the monument in their third field campaign and report finding an almost perfect cardinal orientation, describing the earlier published figure of 12° north-west as a completely wrong value and citing the episode as the demonstration of why local instrumental measurement was necessary. Their table records azimuth 0° on a level horizon with a declination of 60°, and gives the Nile at Seila as running 2° from north, so the cardinal and river-parallel readings very nearly coincide there in any case. Their stated method is to measure along all four faces and from both sides, cross-checked against earlier data over four seasons of fieldwork, noting that magnetic alteration is not expected in the limestone and sandstone terrain of the Nile Valley. The cardinal value is adopted here as a correction of the older figure rather than as one of two competing measurements. A note on how this table should be read. Belmonte and colleagues record two orientations for most of the monuments, and both are given above. The first is the face closest to north, from which the declination δN follows. The second, where present, is a separately measured line — marked a* in their table — carrying its own declination δ*, and it is this second line that usually bears the astronomical interpretation. At Elephantine the second axis at 73° gives the New Year sunrise; at Naqada the axis at 114½° gives Sopdet; at el-Kula the axis at 1¼° gives Meskhetyu at its circumpolar threshold. Angular heights marked with an asterisk in the original are observability thresholds rather than surveyed horizon profiles: Belmonte notes, for instance, that Sopdet must reach at least 2° for its heliacal rising to be seen. All values here recompute from latitude, azimuth and angular height to within about half a degree, consistent with the ±½° precision the authors state for their compass and clinometer measurements. El-Kula's primary axis declination of 40.5° corresponds to no prominent stellar target at 2570 BCE and is best understood as a function of the quarter-cardinal geometry itself — the primary axis is the direct output of the 45° rotation that defines the quarter-cardinal family, while the secondary axis (δ* = 66.75°) represents the discrete astronomical intention toward Meskhetyu at its lower circumpolar threshold.

The orientation of el-Kula toward Meskhetyu --- the Bull's Foreleg, the Egyptian name for Ursa Major --- is not an isolated astronomical datum. It is the architectural endpoint of a tradition with documented antecedents spanning the pastoralist Sahara. The circumpolar emphasis at el-Kula connects directly to the astronomical complex at Nabta Playa, where Malville et al. (2008) documented a shaped 2--3 ton "cow-stone" facing slightly west of north toward the circumpolar

region, megalithic alignments oriented to bright stars, and cattle offerings under stone tumuli, including a complete young cow in a clay-lined, roofed chamber. Malville and colleagues have proposed that the alignments were installed in two periods, about 4600–4200 BCE and about 3800–3400 BCE; the site's most recent comprehensive publication reports both and qualifies the second, matching the first to the dating of the Megalith Builders while judging the younger window one that "would be too recent to fit even the most recent ages of these desert dwellers" (Schild et al. 2025: 139). The earlier window is the one this paper relies on. The most recent comprehensive publication of the Nabta Playa ceremonial landscape (Schild et al. 2025) includes dedicated chapters on megalithic alignments and a stone installation interpreted as a possible solar calendar, confirming that astronomical hypotheses remain central to the site's ongoing study. The excavators explicitly linked the site's persistent northern orientation to the later Egyptian concept of the Imperishable Stars --- the *ikhemu-sek*, the circumpolar realm of eternal life where Meskhetyu revolves. Malville et al. (2008) state this connection explicitly: "The northern circumpolar region of the sky is that realm where stars never set, and, later in dynastic Egypt, it became identified as the realm of eternal life."

The same circumpolar tradition may be reflected in the internal architecture of the 4th Dynasty pyramids themselves. Edwards (1981) has argued that the northern air-shaft of the Great Pyramid was designed as a substitute corridor targeting the circumpolar stars, specifically α Draconis at its lower culmination, and that the Second Pyramid's channels were abandoned because its descending corridor already served this function. If this interpretation is correct, the architectural encoding of circumpolar orientation — documented at Nabta Playa, measured at el-Kula, and arguably present in the internal design of the Great Pyramid — spans the entire period from the Saharan Neolithic to the 4th Dynasty, consistent with the model of continuous tradition proposed here.

Independent evidence for the presence of astronomical knowledge in Upper Egyptian communities during this interval comes from the rural cemetery of Adaïma, located near Hierakonpolis. Alcouffe et al. (2025) have documented three focal tombs spanning the First through Third Dynasties with precise orientations to the heliacal rising of Sirius and the winter and summer solstices. The earliest, dating to the early First Dynasty, predates the MSP program by several centuries — confirming that celestial orientations were embedded in local ritual practice in Upper Egypt well before the pyramid form was deployed as a vehicle for astronomical encoding. The authors note that the precision of these alignments "suggests the involvement of specialists, possibly in rituals or astronomy" (Alcouffe et al. 2025, p. 26), consistent with the existence of a distributed astronomical knowledge base in the region during the period the present paper proposes was the formative interval for the Meskhetyu tradition.

The excavators of Nabta Playa thus draw the line from the site's persistent northern orientation — cattle burials, shaped stones facing north, megalithic alignments to northern stars — to the later Egyptian concept that Meskhetyu embodies. El-Kula's orientation is the architectural expression of that same tradition at the Nile Valley endpoint. The identification of Ursa Major (the Bull's Thigh) as a target at Nabta Playa is documented in the literature (Haynie 2015; Malville et al. 2008). The chain from Nabta's circumpolar tradition to el-Kula's specific Meskhetyu orientation remains inferential, but the continuity of northern-oriented cattle ritual across the corridor provides converging evidence.

The following astronomical argument depends on Belmonte et al.'s (2005) measurement of el-Kula's secondary axis. No independent replication of this measurement has been published as of 2026, nor has any archaeoastronomical team reported an attempt. Prediction 7 is designed to address this.

The interval between Nabta Playa's terminal phase and el-Kula's construction is approximately 800 years — comparable to the span between Egyptian unification (c. 3100 BCE) and the first stone inscription of the Pyramid Texts (c. 2345 BCE), which conventional Egyptology bridges through oral tradition and institutional memory. This interval does not represent an absence of evidence. The Fezzan corridor, through which the genetic and cultural trail runs from the western Sahara to the Nile, contains documented ceremonial architecture carrying the same vocabulary, earlier than this window. Gauthier and Gauthier (2004) surveyed 172 circular monuments — "corbeilles" and large stone circles — across 86 sites on the Messak Settafet plateau. Excavated examples include the corbeille at Site 556, whose engraved stele and burnt cattle offering are dated 5290 ± 40 and 5150 ± 110 BP, and a standing stone at In Habeter IIIa in the Wadi Mathendous, raised over the remains of a slaughtered adult bull dated 5213 ± 80 BP (di Lernia 2006) — all within the Middle Pastoral span of the Messak cattle ritual that the excavators date to 6080–5120 BP, c. 5200–3800 BCE (di Lernia et al. 2013). A hearth inside a large stone circle at Tilizaghen gives a slightly later date, 4915 ± 80 BP (van Albada and van Albada 2000: 44). These structures feature circular stone architecture, in at least one excavated case an inner ring within an outer one (di Lernia and Gallinaro 2010), central stelae engraved with cattle and ovaloid motifs, and burned cattle remains — the same vocabulary of stone monuments and cattle ritual documented at Nabta Playa, and of cattle ritual later at Hierakonpolis HK6. The stelae orientations have been systematically measured, with published azimuth data concentrated toward the eastern horizon — though the Gauthiers note outliers that do not fit solar or lunar patterns. The Gauthiers' survey appeared in an association bulletin rather than a peer-reviewed journal, and the monuments have since been treated in the refereed literature. Di Lernia and Gallinaro (2010) excavated and recorded engraved stones from circular platforms on the Messak Settafet used for animal sacrifice, and report that Pastoral-style rock art, characterised by outline drawings of cattle, appears on upright stones incorporated into the platforms in the period 5430–5150 BP and probably earlier. That account independently confirms the essential features on which the argument here depends: circular monuments, upright engraved stelae built into them, cattle imagery, and animal sacrifice, in the central Sahara during the fifth millennium BCE.

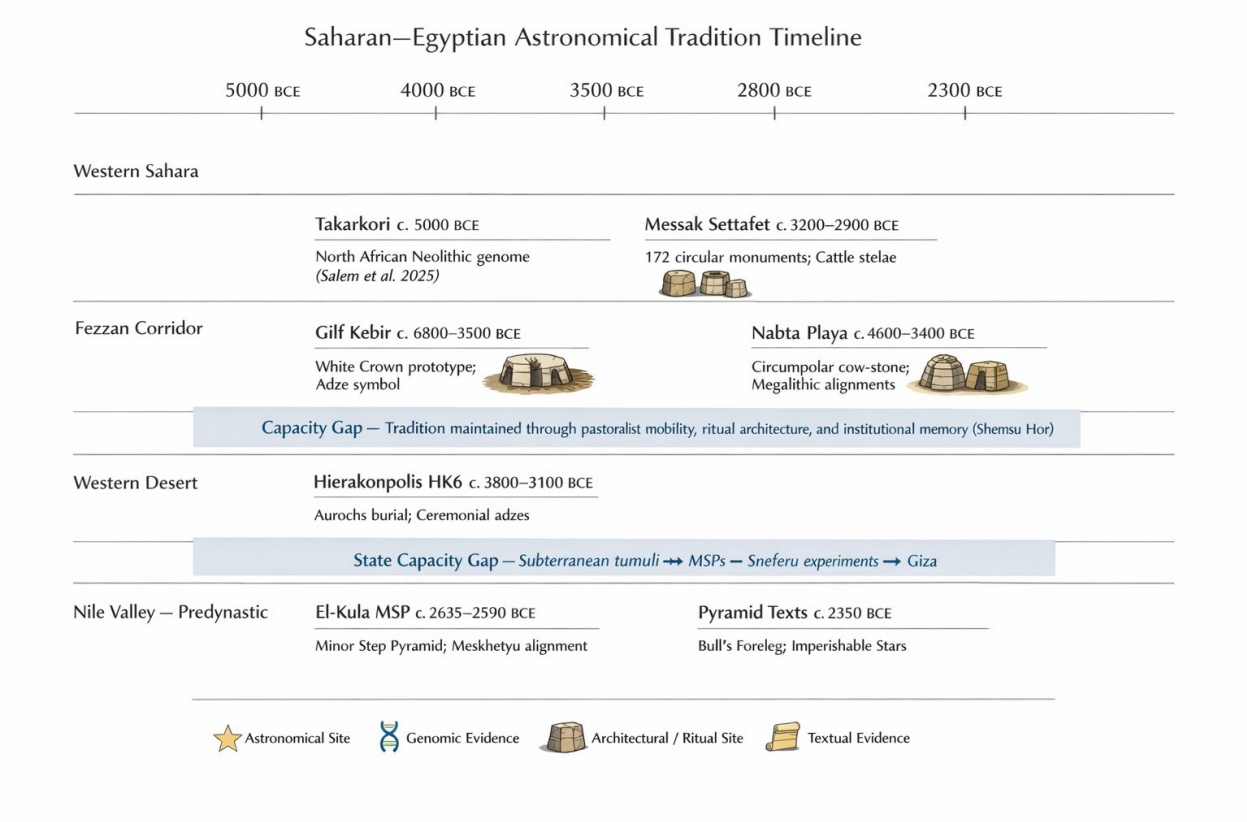
Critically, these monuments belong to a broader pattern of directional ritual behavior documented across the eastern and central Sahara during this period. At Nabta Playa, the articulated young cow beneath tumulus E-94-1n lay with its spine north–south and its head to the south, dated 6480 ± 270 BP; in the Aïr of Niger, articulated cattle burials consistently face east, and later, at In Tuduf (c. 3500 BP), the animals lie east–west with the forequarter to the east, like the humans buried at the same site (Paris 2000, cited in di Lernia 2006). The axis differs from region to region, but the placement is deliberate in each case. This is the practice Paper II calls the herd for the dead (Levy 2026b): cattle placed in death as an ordered deposit oriented toward a focus — the human dead or the tomb — rather than toward a fixed compass direction. The north–south placement at Nabta falls in the same broad window in which Nabta Playa's megalithic alignments targeted northern circumpolar stars. The most recent comprehensive publication of the Nabta Playa ceremonial landscape (Schild et al. 2025) documents the full extent of megalithic alignments and cattle burials, and has been interpreted by its excavators as an early expression of ceremonial traditions that may have contributed to later Nile Valley practices.

This directional pattern was not unique to Saharan pastoralists. Randall-Maciver and Mace (1902) documented that Predynastic graves at El Amrah were consistently oriented north-south, with the body laid head to the south and facing east — indicating that a north-south ritual axis was already an established feature of Nilotic burial practice before the MSPs were built. The

cattle-cult complex documented at Nabta Playa has been identified as an early expression of the tradition that would evolve into the Hathor cult — the bovine sky goddess whose iconography, including the cow-with-disc motif, emerges in the Nile Valley in the Predynastic period (Malville et al. 2008; Hassan 1992). This connection runs through the Bat goddess tradition that centres on Hierakonpolis and Naqada in the Predynastic period, providing a theological chain from Nabta's cattle-centred circumpolar practice to the same cattle-Meskhetyu nexus the paper documents at HK6 and el-Kula.

Further east along the corridor, the rock art of Gilf Kebir (Cave of Swimmers and Cave of Beasts, the Wadi Sura rock art tradition dated c. 6500–4400 cal BCE; Riemer 2013) documents ritual iconography that Bárta (2014) identifies as direct precursors to Pharaonic kingship. A running figure wears a conical headpiece resembling the White Crown of Upper Egypt and holds an adze-shaped tool — the same adze form that matches the Meskhetyu asterism and appears among the ceremonial equipment from the Hierakonpolis Main Deposit. Bárta argues this figure is a Sed Festival prototype, the ritual of royal renewal in which the king's celestial authority was reaffirmed. The same cave complex contains a composition of a white female figure supported by a red male figure, which Bárta interprets as an early formulation of the Nut-Gebe cosmology — the sky goddess and earth god whose separation structured the Egyptian cosmic order.

This reading is contested, and the disagreement should be stated. Rudolph Kuper, who published the definitive site volume for the Cave of Beasts, concludes that in light of the excavated evidence it appears highly speculative that a direct link exists between the cultural concepts displayed in the Wadi Sura imagery and those of the Nile Valley cultures. Bárta's identifications are therefore a minority position held against the principal publisher of the corpus, and the present paper follows Bárta while recording that objection. Two points limit the damage. First, Kuper's objection is to the derivation of specific Egyptian motifs from specific Saharan images; it is not an objection to the movement of Gilf Kebir populations toward the Nile under increasing aridity, which Bárta and Kuper both accept and which is the only element the corridor argument strictly requires. Second, the chronologies differ: Bárta places the relevant panels at roughly 9000–7000 BP, while the Wadi Sura project assigns the prevailing hunter-gatherer art to approximately 6500–4400 cal BC, with the cattle-pastoralist style beginning around 4400 BC. The iconographic claims are accordingly presented here as Bárta's interpretation rather than as established readings, and Prediction 5 is designed to test the orientation question independently of them. The broader interval between Nabta Playa and el-Kula is examined in Paper II (Levy 2026b). For the present argument, the critical point is that the Meskhetyu orientation at el-Kula does not occur in isolation: it appears at the site where ground-level bull ritual is independently documented at HK6. The intermediate corridor thus contains not only cultural continuity — concentric geometry, cattle ritual, and kingship/adze motifs — but also evidence of directional continuity: the same north-south axis that structured ritual practice at Nabta Playa and that would later be encoded in the secondary axis of el-Kula was already carrying ritual significance at sites in the Fezzan and central Sahara during the critical interval. This does not by itself demonstrate astronomical transmission; Prediction 3 is designed to test whether Meskhetyu was specifically targeted at these intermediate sites. What the available evidence now shows is that the directional framework within which such tracking would have occurred — north-south ritual orientation associated with cattle — was already established across the corridor before the MSPs were built. The monument itself waited for sufficient state capacity.


Saharan–Egyptian Astronomical Tradition Timeline
5000 BCE
4000 BCE
3500 BCE
2800 BCE
2300 BCE
Western Sahara
Takarkori c. 5000 BCE
North African Neolithic genome
(Salem et al. 2025)
Messak Settafet c. 3200–2900 BCE
172 circular monuments; Cattle stelae
Fezzan Corridor
Gilf Kebir c. 6800–3500 BCE
White Crown prototype;
Adze symbol
Nabta Playa c. 4600–3400 BCE
Circumpolar cow-stone;
Megalithic alignments
Capacity Gap — Tradition maintained through pastoralist mobility, ritual architecture, and institutional memory (Shemsu Hor)
Western Desert
Hierakonpolis HK6 c. 3800–3100 BCE
Aurochs burial; Ceremonial adzes
State Capacity Gap — Subterranean tumuli ↠ MSPs ↞ Sneferu experiments → Giza
Nile Valley — Predynastic
El-Kula MSP c. 2635–2590 BCE
Minor Step Pyramid; Meskhetyu alignment
Pyramid Texts c. 2350 BCE
Bull's Foreleg; Imperishable Stars
Astronomical Site
Genomic Evidence
Architectural / Ritual Site
Textual Evidence

El-Kula's Orientation: The Quarter-Cardinal Meskhetyu Alignment

El-Kula's north face sits at azimuth 316.25° — 44° west of north. This is a quarter-cardinal orientation: the pyramid's axis of symmetry is rotated 45° from the cardinal directions. Belmonte, Shaltout and Fekri (2005) measured the secondary axis at a declination of approximately 66.75° at an altitude of roughly 2° — consistent with a circumpolar star barely clearing the northern horizon at the lower culmination threshold of Meskhetyu, the Bull's Foreleg asterism (Ursa Major). They used declination histograms to confirm that this orientation falls within a statistically significant peak, consistent with intentional targeting rather than random placement. They group el-Kula explicitly with El Ghoneimiya and Sinki as the "quarter-cardinal family," all three oriented toward the lower circumpolar threshold of Meskhetyu at approximately 2570 BCE. The area between El Ghoneimiya and el-Kula was, at that epoch, "the region of Egypt where Meskhetyu ceased to be circumpolar when travelling south" (Belmonte et al. 2005: 9). The pyramid at Hierakonpolis was built at the precise latitude where this constellation reached its astronomical threshold. In their 2023 synthesis, Belmonte and Lull reaffirm this analysis, noting that "the orientation of the pyramids of the quarter-cardinal family, such as el-Kula and Sinki, could be explained if they were orientated towards the lower culmination of Meskhetyu, the Bull's Foreleg, the most characteristic Egyptian circumpolar constellation" (Belmonte & Lull 2023, p. 390).

Belmonte et al. (2005) identify connections between some MSP orientations and stellar/calendar phenomena that later appear in the Pyramid Texts. They do not trace the origin of this tradition. The present paper proposes, as a hypothesis, that this astronomical tradition originated with Saharan pastoralist populations and was transmitted to the Nile Valley via the

corridor documented in Papers I and II (Levy 2026a, 2026b). Within this model, the astronomical tradition did not originate in Egypt. It arrived with the people, carried through the corridor documented in Papers I–III.

An observation on the orientation families. Belmonte's own figures show that the two axes recorded for the quarter-cardinal monuments are separated by exactly 45°: el-Kula at 316¼° and 1¼°, Sinki at 318¾° and 3¾°, in both cases a difference of 45.00°. For the remaining group the second axis lies at 90° or 270°, the perpendicular face. The two families therefore divide the horizon circle by successive halving — a quarter for the cardinal orientation at Seila, an eighth for the quarter-cardinal group — and both quantities are terms of the same binary series as the Wedjat fractions and the hekat measures discussed in Section 13. Whether that is significant is a separate question from whether it is true, and the limits should be stated. Bisecting a right angle is the simplest operation available to anyone working with a stretched cord, and a builder who halves a quadrant arrives at 45° irrespective of the fractional notation in use; the geometry is therefore consistent with a binary habit of division without evidencing it. The finer terms of the series cannot be tested against this data at all: Belmonte reports a measurement precision of about half a degree, while a sixty-fourth of the circle is 5.625°, so any recorded azimuth will fall within half a degree of some such division by construction, and searching for correspondences at that level would be fitting noise. The residual departures from exact quarter-cardinality — el-Kula 1¼° and Sinki 3¾° from 315° — likewise lie within or near the stated error and are not treated here as encoded values. The observation is recorded because the division of the horizon by halving is the same operation the paper attributes to Egyptian fractional practice elsewhere, not because the orientations independently demonstrate it. Canopus and Meskhetyu: Two Scales of the Argument

Canopus — the navigation star central to the corridor migration argument of Papers I and II — was tested against el-Kula's 316° orientation and found not to match. Canopus's rising azimuth at Hierakonpolis in 2570 BCE is approximately 155.6° and setting approximately 204.4° (computed with the Vondrák et al. 2011 long-term precession model); the pyramid's primary axis (136°/316°) falls roughly 20° short of the Canopus rising point, well outside Belmonte's stated error margin. Meskhetyu, not Canopus, governs el-Kula's orientation.

This is not a weakness. Canopus and Meskhetyu operate at different scales of the argument: Canopus is proposed here to explain the corridor migration route (a geographical gradient; an interpretation, not a finding); Meskhetyu explains the cultural inheritance at the destination site (an astronomical encoding of the bull cult tradition).

The absence of a face-to-face Canopus alignment at the MSPs is, however, consistent with a broader distributional pattern that reinforces the corridor argument. The MSP chain spans latitudes 24.1°N (Elephantine) to 29.4°N (Seila). At approximately 2570 BCE — the construction epoch — Canopus's maximum altitude descends continuously from 10.4° at Elephantine to 5.1° at Seila, reaching 5.1° at Seila and approximately 4.5° at Giza (computed with the Vondrák et al. 2011 long-term precession model; altitude figures are maximum values at upper culmination for 2570 BCE). Canopus would have remained above the horizon at Giza (4.5° at 2570 BCE), dimmed by the air it crossed from −0.74 above the atmosphere to an apparent magnitude of about 2.1 in clean air and 3.2 in moderately dusty air — but the entire MSP chain sits within the latitude band where it appeared highest, consistent with a population for whom this star held navigational significance maintaining their primary settlement nodes within its most prominent viewing zone. No individual MSP face is oriented to Canopus; the Meskhetyu tradition governs

all documented orientations. But the seven provincial pyramids together trace the corridor zone that Canopus defined. The builders were no longer navigating — they had arrived. Canopus is proposed here to explain why these particular sites mattered to the corridor population. Meskhetyu explains what they chose to encode in stone once they were there. (Canopus altitude figures are computed with the Vondrák et al. 2011 long-term precession model for the 2570 BCE epoch and checked against an independent astropy calculation; see zep_tepi_calculations.py (Part 1).)

Canopus and Meskhetyu: Two Halves of a Single System

Canopus and Meskhetyu are not competing stellar traditions but complementary elements of a single orientation system: the Wedjat sky-compass set out in Paper II (Levy 2026b, Chapter 7). In this system, the anatomical components of the Wedjat resolve into a directional schema: the brow (1/8) is oriented southward toward Canopus, marking the origin direction, while the teardrop (1/64) is oriented northward toward the circumpolar region, the domain of the Imperishable Stars whose most prominent asterism is Meskhetyu. This directional mapping is derived from the geometric orientation of the Wedjat components as set out in Paper II, where it is proposed as a reconstructed spatial framework rather than a symbolic association.

During the corridor migration, Canopus functioned as the active navigational anchor — a southern star whose progressively reduced altitude and observational prominence with increasing latitude made it a continuous experiential marker of movement. At the destination, where its observational role diminished, emphasis shifted to the circumpolar stars, particularly Meskhetyu, which remained permanently visible and astronomically stable. At latitudes where Canopus's observational role diminished while circumpolar stars remained permanently visible, any system preserving directional orientation would necessarily privilege the circumpolar axis. This represents not a change in cosmological system but a contextual shift within it: the journey anchor during movement, the destination anchor at settlement.

The MSPs, constructed at the integration sites of the corridor population, encode Meskhetyu because it is the component of the inherited system that remained fully visible and functionally dominant at the new latitude. This dual-anchor structure also offers a reading of the coexistence in Dynastic Egypt of both southern stellar traditions (e.g., Canopus-oriented temples) and circumpolar "imperishable" star theology, which have otherwise been treated as independent systems.

Meskhetyu in the Pyramid Texts

Meskhetyu is not merely a navigational marker. In the Pyramid Texts (first inscribed under Unas, c. 2375–2345 BCE, but preserving oral traditions of the Predynastic period), Meskhetyu is the Bull's Foreleg asterism. Lull and Belmonte (2006) confirm the identification of *mshtyw* — the Bull's Foreleg or Meskhetyu — with the asterism of the Plough (Ursa Major), an identification first established in the nineteenth century by Le Page Renouf. Belmonte and Lull (2023, p. 252) state the identification unequivocally: "Without the slightest doubt, this asterism is none other than the Plough or Big Dipper, the most characteristic element of the constellation of Ursa Major." The specific identification is with the seven-star asterism known today as the Plough or Big Dipper (Dubhe, Merak, Phecda, Megrez, Alioth, Mizar, Alkaid).

The identification rests on three independent lines. First, the circumpolar status of these stars matches the 'Imperishable Stars' category in Egyptian astronomy. Second, the documented linkage between Meskhetyu and the adze used in the Opening of the Mouth ceremony — the shape of the adze matches the Plough asterism, and the Quibell & Green ceremonial adzes

from the Hierakonpolis Main Deposit provide archaeological confirmation of this connection. Third, Belmonte's stellar declination calculations for Old Kingdom orientation schemes are consistent with Ursa Major as the reference asterism (Belmonte, Shaltout & Fekri 2005; Locher 1985). The seven stars of Meskhetyu are unambiguously identified in the Dendera zodiac and related astronomical texts.

Belmonte and Lull (2023, p. 252) further document the evolution of the constellation's iconography in the Egyptian record itself: "The earliest surviving mentions of Meskhetyu... refer to this constellation with the adze determinative... Later, Meskhetyu is written with the bull's leg determinant, thus recognizing the way in which this constellation was also observed." This dual identity — adze and bull's foreleg — is confirmed on Middle Kingdom coffin lids, where "Meskhetyu is represented in the shape of a bull's leg, and the seven stars indicated in it lend it a shape that reminds us of the Wagon" (Belmonte & Lull 2023, p. 252). The iconographic evolution from adze to bull's foreleg traces the same symbolic chain — implement, animal, constellation — that this paper argues connects the pastoralist bull cult at HK6 to the astronomical orientation at el-Kula.

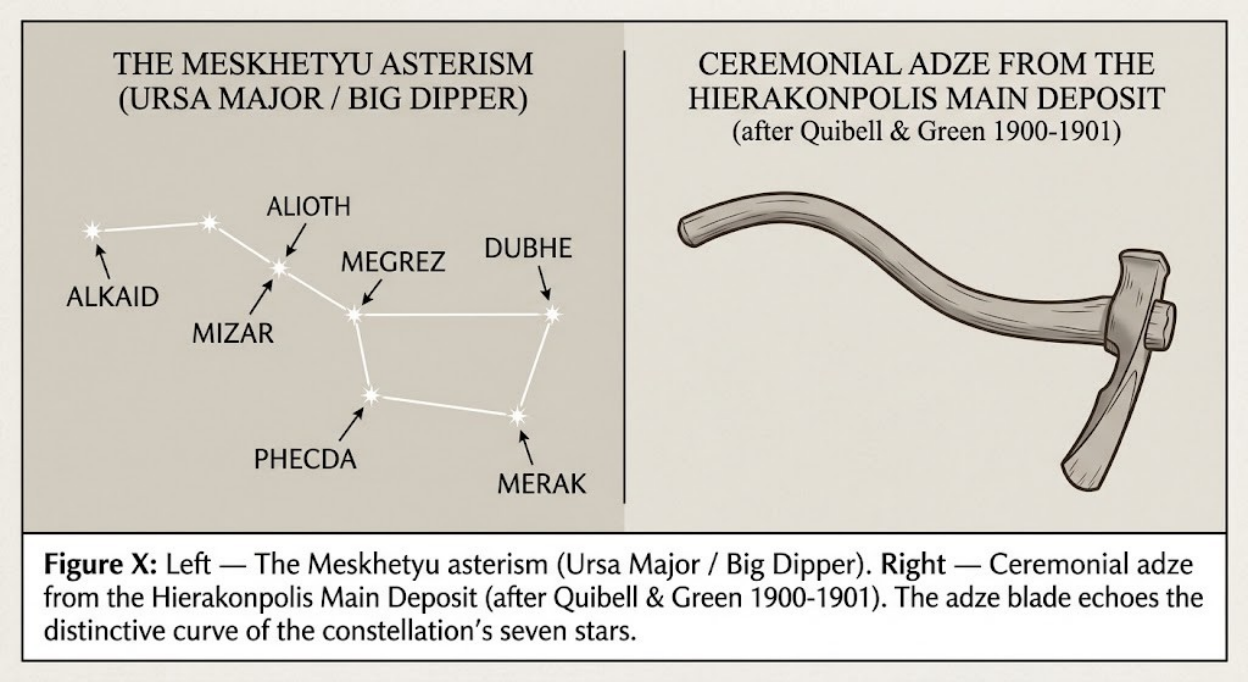


Figure X: Left — The Meskhetyu asterism (Ursa Major / Big Dipper). **Right** — Ceremonial adze from the Hierakonpolis Main Deposit (after Quibell & Green 1900-1901). The adze blade echoes the distinctive curve of the constellation's seven stars.

One evidential limit must be stated before this chain is relied upon. The earliest surviving text naming Meskhetyu alongside the circumpolar stars is Pyramid Texts Utterance 302, in the pyramid of Unas at the end of the Fifth Dynasty, where the Enneads are said to have purified themselves for the king as Meskhetyu, the Imperishable Stars. The earliest surviving depiction of the constellation as a bull's foreleg is later still: the interior lid of the coffin of Idy from Asyut, of the First Intermediate Period, captioned Meskhetyu in the northern sky. Both postdate the Minor Step Pyramids, the first by some two and a half centuries and the second by some five hundred years. The association argued here for the late Third and early Fourth Dynasties is therefore not directly attested in a contemporary source, and rests on the retrojection of a later documented tradition. That retrojection is standard practice in the field, since most Egyptologists accept that the ideologies expressed in the Pyramid Texts can be projected back to the Fourth Dynasty with appropriate caution, and it is the same structure of argument this paper makes elsewhere about the interval between practice and its surviving record. It is nonetheless an inference rather than

an attestation, and is marked as such. Krauss (1997, pp. 120–121) identifies the Imperishable Stars (*jhmw-sk*) with the circumpolar stars — the same region of the sky targeted by el-Kula's secondary axis ($\delta^* = 66.75°$ at $h^* = 2°$). Meskhetyu is the most prominent circumpolar asterism in this region, associated with the eternal afterlife of the king and identified with the celestial adze used in the Opening of the Mouth ceremony, through which the mummy of the deceased was restored to life.

The direction of this symbolism carries implications for the transmission argument. One qualification should accompany any use of Priskin's study. His wider argument is that the ovoid bull of Senenmut's ceiling and the standing bull of Seti I are not Ursa Major at all but separate constellations elsewhere in the northern sky, so that at least three different figures bore the name meskhetyu. Belmonte and Lull reject his method, warning that planetarium software cannot identify Egyptian constellations without supporting astronomical and textual argument. Lull himself cautions that the Egyptians did not always use the same method to set the north–south axis of a pyramid, listing secondary alignment to an already-oriented earlier pyramid, primary alignment on the culmination of circumpolar stars such as those of Meskhetyu, and solar procedures among the possibilities; the spread of measured orientation values, in his view, rules out a single universal technique. That caution is adopted here. This paper does not rely on Priskin's reassignments. What is taken from him here is confined to points on which the field agrees: the identification of the foreleg with the seven stars of Ursa Major, the Pyramid Texts placing it among the imperishable ones, the observation of the constellation in foundation ritual, and the homophony of the adze with the constellation name. His own conclusion that the term had a loose semantic field, or was inherently multivalent, is in any case consistent with the caution exercised below. The mythological account of how the foreleg came to be in the northern sky survives in full only in later texts, but its Old Kingdom origin is secured by Pyramid Texts 61 (§42), where Osiris is bidden to take the foreleg of Seth which Horus cut off from him. Belmonte and Lull record that the earliest attestations of Meskhetyu carry the adze determinative and that the bull's-foreleg form appears later, so the surviving Egyptian textual sequence runs from implement to animal. The northern-orientation tradition at Nabta Playa, however, is documented through the Late and Terminal Neolithic, from approximately 5500 BCE (Malville et al. 2008), centuries before any Egyptian adze iconography. This chronological priority is consistent with the hypothesis that a pastoralist population named the circumpolar asterism for the most symbolically charged animal in their world — its seven stars trace the shape of a bull's foreleg — and that the ritual adze was subsequently shaped to echo that constellation, a materialization of celestial knowledge in physical form. If this sequence is correct, the Opening of the Mouth ceremony encodes, in its very instrument, the circumpolar astronomical tradition this paper traces from the Saharan pastoral world through HK6 to the pyramid tradition.

What remains absent is a dedicated archaeoastronomical survey of the intermediate sites for circumpolar orientations specifically. Prediction 3 is designed to address this: systematic survey of the Predynastic ceremonial structures at HK6 and reanalysis of the Messak stelae orientations for Meskhetyu or related circumpolar targets would determine whether the astronomical tradition was actively encoded in architecture during the interval, or whether it was carried by other means — oral tradition, ritual practice, and institutional memory — until the state capacity developed to render it in monumental stone.

The astronomical orientation of the MSPs participates in a broader and deeply ancient Egyptian tradition of aligning sacred structures to celestial targets. The "stretching of the cord" ceremony, depicted on the walls of the Ptolemaic temples of Hathor at Dendera and Horus at Edfu, "repeatedly mention Meskhetyu... as the appropriate celestial target" toward which the pharaoh

looked when fixing a temple's orientation (Belmonte & Lull 2023, p. 15). Lull (2008) sets out the primary texts. The foundation inscription of the Edfu temple, founded by Ptolemy III in 237 BCE, has the king declare that he holds the stake and takes the grip of the mallet, measures with Seshat, turns his face to the course of the stars and directs his eyes to Meskhetyu, while Sek-Aha — the indicator of time, Thoth — is at his merkhyt, and thereby determines the four corners of the temple (Edfu II, 31). The Dendera foundation text of Ptolemy XII, from 54 BCE, records that the king stretched the cord with satisfaction and, with his gaze upon the Ach of Meskhetyu, founded the house of the goddess. Lull argues from Belmonte's measured azimuth of 18° that the star sighted at Dendera was Alkaid, the star at the end of the foreleg, which the Senenmut ceiling singles out with a red marker. These are Ptolemaic texts describing a ritual of much greater antiquity, and they name the constellation, the goddess, and the sighting instrument together. The same source confirms that at Dendera and Edfu, "the northern, imperishable, ancient Egyptian constellation of Meskhetyu is advocated as the target the Pharaoh was looking at when fixing the orientation of the temples" (Belmonte & Lull 2023, p. 378). This ceremony, though attested in its surviving textual form only from the Ptolemaic period, preserves a ritual grammar of far greater antiquity. Belmonte and Lull (2023, p. 395) note that their research team has identified predynastic structure HK29A at Hierakonpolis — the same site as the HK6 elite cemetery and 6 km from el-Kula — as "one of the first buildings erected in Egypt to be orientated astronomically." The Meskhetyu orientation at el-Kula therefore does not stand in isolation. It is the monumental expression of an astronomical tradition whose local antecedents at Hierakonpolis predate the MSPs by centuries, and whose ritual form — targeting Meskhetyu — would persist in Egyptian temple foundation ceremonies for the next two and a half millennia.

6. The Chain: Bull on the Ground, Bull in the Sky

The astronomical evidence presented in Section 5 establishes that el-Kula was oriented toward Meskhetyu — the Bull's Foreleg — at its circumpolar threshold. That orientation does not occur in isolation. It appears at Hierakonpolis, the same site where ground-level bull ritual is independently documented across multiple categories of evidence. This section examines the local convergence: the bull on the ground and the bull in the sky at the same place, within a continuous tradition of ritual activity spanning more than a millennium.

The full pastoralist material package documented at HK6 — wild bull burials, sheep horn modification, ceremonial adzes matching Meskhetyu — has been detailed in Section 2. The ceremonial centre HK29A was in continuous use from Naqada IIA through Dynasty 1 at the same location, producing 37,500 animal bones from ritual sacrifice including cattle (Friedman 2009, JARCE 45: 79–104). The identification of HK29A as a ceremonial centre rests on architectural, archaeological and macrobotanical evidence, though alternative functions as a feasting or butchery site have also been proposed. Nor is HK29A the only such structure at the site: excavations at HK29B, some forty metres to the north, revealed what the excavators describe as one of the first monumental cultic compounds in Egypt — a palisade trench running nearly fifty metres, with postholes large enough to have carried standards or timber figures six to seven metres high, across two successive building phases. Whichever reading is preferred, the excavated structure at HK29A is substantial: a walled oval courtyard some 45 by 13 metres, entered on its southern side through a monumental gateway framed by four large acacia posts, and renovated repeatedly across the five centuries of its use. Friedman draws from the wider HK6 evidence the conclusion that complex social and religious arrangements were already in place at this early date, with leaders able to marshal labour and exotic resources to express their authority. More directly relevant to the present argument, the HK29A structure has been shown to be oriented quarter-cardinally, and it has been argued that its axis was rotated 45° from an original north–south line by the simultaneous transit method, using Phecda and Megrez

in Ursa Major (Belmonte, Shaltout & Fekri 2008: 190–95; Szwec 2022: 99). The significance for this paper is direct. The quarter-cardinal geometry later found at el-Kula and Sinki, and the specific star pair later used to establish true north at Seila, are both already present at Hierakonpolis in a Predynastic ceremonial structure — at the same site, and in the same tradition, roughly a millennium before the minor step pyramids were built. Tomb 100, which postdates the main HK6 activity (late Naqada II to early Naqada III, about 3500–3200 BCE), depicts hooved animals in corrals alongside scenes read as royal authority over the animal world (Case and Crowfoot Payne 1962). The practice the scene is taken to depict is independently attested in the Western Desert: Hendrickx and colleagues (2009) document Late Predynastic and Early Dynastic rock art scenes of Barbary sheep hunting that turn on the capture rather than the killing of wild animals, in the region the corridor model concerns. Two caveats attach. Huyge (2014) argues that the surviving composition is two-phase, an original Naqada IIC scheme modernised in Naqada III, so the date of any individual element cannot be assumed; and the corralled animals have also been read as domestic livestock rather than captured wild cattle. The tomb itself was lost after excavation and its finds were disturbed in transit, which is why Crowfoot Payne (1973) published a separate confirmation of the record. At Nabta Playa, the most recent publication of the ceremonial complex (Schild et al. 2025) documents cattle burials beneath stone tumuli in the "Wadi of the Sacrifices" and over 200 additional stone structures, indicating that the symbolic association of cattle with monumental ritual architecture was already established in the Saharan pastoralist world before the corridor dispersal reached the Nile Valley.

The bull-foreleg motif is materially attested at Hierakonpolis by carved ivory bulls' legs from the Main Deposit (Quibell & Green 1900, Plate XVI, figs. 6–8), dated to Dynasty 0 (c. 3100 BCE). These elite ritual or furniture elements, found alongside ceremonial adzes whose shape matches the Meskhetyu asterism (Plates XLVI–XLVIII), demonstrate that the bull-foreleg form was already an established symbolic element at the Shemsu Hor centre at unification — approximately 700 years before its codification as the Meskhetyu constellation in the Pyramid Texts and 500 years before the construction of the el-Kula provincial pyramid. A geometric morphometric comparison of the ceremonial adzes with the Big Dipper asterism is proposed as a future test of this link. No such analysis is presented here, and the correspondence remains a visual impression rather than a measured result.

Meyrat (2017, 2021) documents the "Bull of Nekhen" as a royal achievement motif — the king's defeat of a wild bull celebrated at Hierakonpolis — and traces the origins of the Apis cult to Nekhen. The last king of the 2nd Dynasty, Khasekhemwy (c. 2690 BCE), built a monumental mud-brick enclosure at Hierakonpolis whose niched gatehouse belongs to the same royal architectural idiom that Kemp traces forward into the Step Pyramid complex (Kemp 2018: 102, 104). Into this continuously active ritual landscape, the provincial pyramid at el-Kula was inserted at the 3rd–4th Dynasty transition, its secondary axis oriented to Meskhetyu at the precise latitude where the constellation reached its circumpolar threshold (Belmonte, Shaltout and Fekri 2005).

The ritual circuit proposed here is the most interpretively layered element of the argument, and depends on the synthesis of independently attested components rather than direct textual confirmation. Each component is documented; their assembly into a single ritual is an inference.

The evidence at HK6 and the astronomical orientation of el-Kula are not necessarily independent. The connection between them can be formalized as a four-link inferential chain: (1) HK6 bull ritual → Opening of the Mouth ritual (inferred — the ritual is first documented in the Pyramid Texts, c. 2345 BCE, later than the MSPs); (2) Opening of the Mouth ritual → meskhetyu adze (documented — Otto 1960; Roth 1993, JEA 79: 57–79); (3) meskhetyu adze

→ Meskhetyu constellation (documented — the adze shape matches the Plough asterism, though the correspondence is visual and qualitative rather than mathematically quantified; Lull and Belmonte 2006); (4) Meskhetyu constellation → el-Kula orientation (measured — Belmonte, Shaltout and Fekri 2005, but awaiting independent replication; see Prediction 7). Two links are documented, two are inferred. The chain is materially strengthened at link (3) by the ivory bulls' legs from the Main Deposit, which confirm that the bull-foreleg form was an established elite motif at Hierakonpolis at least seven centuries before the Pyramid Texts — independent of the adze-constellation correspondence, and therefore an additional line of evidence rather than a circular reinforcement.

The two inferred links are testable. Link 1 (bull ritual → Opening of the Mouth) would be strengthened by direct archaeological evidence of Opening of the Mouth ritual activity at Hierakonpolis contemporary with the MSP construction period (c. 2613–2590 BCE); targeted excavation of ritual deposits at HK29A or el-Kula dating to the 3rd–4th Dynasty transition could provide this. Link 3 (adze shape → constellation shape) no longer rests on visual comparison alone. Nemes (2020), in the only study devoted to Meskhetyu across the mortuary corpus, locates the correspondence in the writing of the texts themselves: the determinative of the msḫtjw-adze, Gardiner U19A, "appeared already in the Pyramid Texts [Spell 302 (Pyr. 458b-c)] and later in the Coffin Texts [Spell 61 (CT I, 264c)] as the determinative of the asterism, hereby providing a clear reference to their early interrelatedness" (a point he credits to Wallin 2002), and the relation runs both ways, "meaning that the adze could actually appear with the determinative of a bull's foreleg (F23)". The same word names both, and in the Old Kingdom the same sign writes both. This supplies the specific textual locations for what Belmonte and Lull (2023, p. 252) state in general terms above, and moves Link 3 from resemblance to orthography. A quantitative geometric morphometric analysis of the Hierakonpolis ceremonial adzes against the asterism would still add a measured correspondence to the written one.

This does not weaken the argument — it identifies precisely where it rests on evidence and where it rests on consilience, and specifies what would move the inferred links toward documentation. The argument does not require every link in this chain to be independently proven. The convergence of bull cult, adze imagery, Meskhetyu, and architectural orientation at a single site is more parsimoniously explained by continuity of symbolic tradition than by independent coincidence.

The ritual's material precursors are older than its textual documentation. The psš-kf knife, associated with the Opening of the Mouth, appears in elite burials from Dynasty 1 (Roth 1992), suggesting ritual elements predate the Pyramid Texts by centuries, though the specific Meskhetyu/bull-foreleg link is first textually attested later. A wooden model adze recovered from a Predynastic grave at El Amrah (grave b 202; Randall-Maciver and Mace 1902) shows that the adze form was already present in funerary contexts before the Hierakonpolis ceremonial adzes and centuries before the Opening of the Mouth ritual was textually codified. This temporal priority matters for the argument: during the Dynasty 3–4 period of the MSPs, the meskhetyu adze was in use specifically for the consecration of royal statues at sacred structures — its older, original function, contemporary with the provincial pyramid program. Roth (1993: 75) argues that the adze entered the mortuary ritual only later, from this earlier statue and temple consecration tradition. Roth's sequence runs from the fingers, to the finger-shaped nṯrwj-blades, to the adze, which she places as a Sixth Dynasty import from the statue ritual; she does not argue for an astronomical origin, and the inference that one is primary does not follow from her evidence alone. What does bear on the question is the ritual's own vocabulary: in the Opening of the Mouth the adze-shaped blades are themselves named meskhetyu (Otto 1960, Episode 26). The implement therefore carries the constellation's name within the liturgy, which is consistent with its having been named after an already established celestial referent rather than

lending its name to one. Priskin reaches the same connection independently, observing that the shape of the constellation is perhaps better reflected by the adze used in the Opening of the Mouth than by the foreleg, since the tool bears the homophonous name meskhetyu (Priskin 2019: 160, citing Roth 1993: 70), and noting that the Middle Kingdom coffin lids show the foreleg containing seven stars arranged in a pattern resembling the Plough. That remains an inference, but it is an inference from the ritual text rather than from the order in which implements entered the rite.

In the Pyramid Texts the bull's foreleg enters the offering ritual identified with the thief of the Eye: it is presented with the words "Osiris Unis, here is the one who stole Horus's eye" (PT 126; Allen 2015: 27), and in the Opening of the Mouth of Pepi II the king's mouth is parted "with the one who stole Horus's eye," the offering being one foreleg (PT 20; Allen 2015: 248). Edwards (1995) observes that the foreleg's shape resembles that of the adze used to open the mouth. The foreleg, the adze and the Eye of Horus thus meet in the oldest funerary ritual, as foreleg and adze meet in Meskhetyu, whose earliest mentions carry the adze determinative (Belmonte and Lull 2023: 252). The foreleg offering is itself Predynastic, laid in Naqada graves alongside green eye paint (Sherkova 2023). In a spell of Unas the West greets the king as "eye-painted pillar, bull of the sky" (PT 254; Allen 2015: 47).

Two further objects bear on the association and are worth setting beside the Hierakonpolis material. The first is the Gerzeh Palette (Cairo JE 43103), from tomb 59 at Gerzeh and dated Naqada IIC–D, roughly 3500–3200 BCE. It carries a bovine head with five stars worked into the composition, two at the horn tips, one above the head and one to either side of the ears, and is generally read as evoking one of the bovine deities identified in this period with the heavens. It is contemporary with Tomb 100 and earlier than the Main Deposit, and it places the conjunction of cattle and stars in Predynastic Egypt as an object rather than an inference. It does not stand alone. Szwec (2022) assembles ten examples of what she terms the Celestial Cow emblem, four of them from Hierakonpolis: a pot-mark on a red polished bowl from Tomb 16 in Cemetery HK6, dated Naqada IC–IIA and identified as possibly the earliest attestation of the motif; an incised ostracon from the HK29A ceremonial centre, Naqada IID2–IIIA; the Narmer Palette; and the rim of a porphyry bowl from the Main Deposit, First Dynasty, now Petrie Museum UC 16245, which she notes stands alone as the only known case combining stellar imagery with the Celestial Cow emblem in that period. The Main Deposit therefore yields not only the ivory bulls' legs but an object on which bovine and stellar elements are carried together, in a spatial arrangement she describes as closely similar to the Gerzeh Palette. The second lies at the other end of the sequence. The shaft of Hetepheres I at Giza, sealed by Khufu's own mortuary workshop, contained in a niche the remains of an offering: three leg bones of a bull wrapped in a red mat, two wine jars and a horned skull. A bull's foreleg deposited in the necropolis of the king whose pyramid this paper treats as the terminus of the sequence is not proof of continuity, but it is the practice itself, still present at the end of the interval. Whether the terrestrial bull ritual and the celestial bull orientation formed a single coherent ritual circuit at Hierakonpolis during the MSP period, or represent parallel expressions of a shared symbolic vocabulary, cannot be confirmed from current evidence and remains an inference. It may be noted, however, that the mechanism of archaeological rediscovery as a driver of cultural transmission — which this paper proposes for the Meskhetyu tradition — has been independently documented elsewhere in the Egyptian record. Miniaci (2024) has argued that Late Middle Kingdom votive figurines (c. 1850–1700 BCE) reflect the rediscovery of Early Dynastic deposits during temple renovations at sites including Hierakonpolis, Elephantine, and Abydos. He finds that the figurines have no precedent in the recent past while their closest comparanda lie in the votive material of the Early Dynastic temples, separated by a gap of over half a millennium, and attributes the resemblance to royal initiatives to preserve and restore Early Dynastic sites, which he suggests led to the

rediscovery and reworking of earlier images. The interval he documents is of the same order as the one argued here, in an unrelated class of material, and with a mechanism attached. It carries a temporal gap comparable to that between the HK6 elite cemetery and the MSP program. While this parallel does not demonstrate that the same process occurred at Hierakonpolis, it indicates that the category of explanation proposed here is methodologically recognized in Egyptian archaeology.

The broader corridor-wide evidential chain — from Nabta Playa through the Fezzan to the Nile — is documented in Papers I and II (Levy 2026a, 2026b); the institutional transmission via the Shemsu Hor is argued in Paper III (Levy 2026c). The temporal gap between local ritual practice and textual codification — a central challenge for any transmission argument — has a documented parallel in the same region. At Adaïma, Alcouffe et al. (2025) identify a 'breaking of the red pots' ritual in a Third Dynasty burial that they argue constitutes 'a local precursor to the later "breaking of the red pots" rite mentioned in the Pyramid Texts of Unas' — a gap of approximately 350 years between material practice and textual documentation.

The authors further note that 'pre- and proto-dynastic elements' are widely recognized within the Pyramid Texts, supporting the view that these texts preserve ritual traditions of considerably greater antiquity than their date of inscription. If a 350-year gap is accepted for the red-pot ritual's transmission from rural practice to royal text, the 400–700-year interval proposed here for the Meskhetyu tradition — from Nabta Playa's circumpolar complex to el-Kula's architectural encoding — is not anomalous. Similarly, the dismemberment and ritual reassembly of an adolescent female in tomb S166 at Adaïma has been interpreted as a narrative prototype — a 'mytheme' — for the later Osiris dismemberment-reassembly mythology (Alcouffe et al. 2025, p. 28), providing a second example of a local ritual practice later codified in state religious texts.

A skeptical reviewer will note the alternative: the MSP builders at el-Kula may have oriented their pyramid toward Meskhetyu without inheriting any knowledge from earlier pastoralist traditions. They had the same sky, the same circumpolar stars, and a cattle-centred culture that could have independently produced the same symbolic associations. This paper grants that such independent re-invention is logically possible. What the consilience argument establishes is that independent re-invention of the same symbol, at the same site, with the same archaeologically documented material culture spanning more than a millennium of continuous ritual activity (HK6, HK29A, Tomb 100, Khasekhemwy), is the less parsimonious explanation. If correct, this circuit would represent a rare case in which astronomical symbolism, ritual practice, and material culture converge within a single documented ceremonial sequence. The hypothesis would be strengthened if future excavation at HK29A or el-Kula yielded direct evidence of Opening of the Mouth ritual activity contemporary with the MSP construction. At present, the connection is plausible and parsimonious but unconfirmed.

The convergent evolution alternative would require the bull cult practices at HK6, the ceremonial adzes matching Meskhetyu, the "Bull of Nekhen" royal ideology, the Opening of the Mouth ritual's bull-foreleg sequence, and the astronomical orientation of el-Kula to Meskhetyu — all to arise independently at the same location across successive periods. While each element is individually possible, their repeated conjunction at a single site with documented institutional continuity is more economically explained by a shared symbolic and ceremonial inheritance than by repeated independent re-invention. This remains a hypothesis of parsimony, not proof. Both transmission and convergent evolution are testable; the predictions in Section 12 are designed to distinguish between them. The argument presented here is not that any single line of evidence demonstrates transmission, but that their convergence at a single site, across a continuous chronological sequence, is more economically explained by inheritance than by independent reassembly.

7. The Full Timeline: From Green Sahara to Giza

The table below presents the complete timeline of the pyramid tradition as this series reconstructs it. This table represents the model proposed in this series; dates and interpretations are approximations and should be read as hypotheses rather than consensus.

The rural cemetery at Adaïma, near Hierakonpolis, provides a continuous archaeological sequence spanning 3500–2600 BCE, documenting the evolution of astronomical funerary orientations from local ritual practice to state-associated forms across the same interval the present model identifies as the transmission and institutionalization window (Alcouffe et al. 2025).

Dates for the Green Sahara and corridor dispersal phases are based on paleohydrological and genomic evidence; Dynastic dates follow standard Egyptological chronologies (Shaw 2000). The 'Shemsu Hor institutionalised' phase is inferred from later textual sources and should be read as part of the model, not as a consensus historical event. Phase Zero — the provincial pyramid program — is highlighted as the layer that resolves the apparent 500-year knowledge gap.

Table 4: Full Timeline — From Green Sahara to Giza

Period / Phase	WHO (People & Institution)	WHAT They Built	HOW / Key Innovation
7000–5300 BCE Green Sahara	**Ancestral Saharan pastoralists**	**Megalithic tumuli**	**Foundation skills**
	Cattle herders; Takarkori genome; social stratification via burial goods; shared astronomical traditions	Stone-covered burial mounds sited away from dwellings; Nabta Playa megalithic alignments (c. 4600–4200 BCE; the possible “Calendar Circle” itself carries no construction date, Schild et al. 2025: ch. 11); Bull's Thigh tracked	Drystone construction; astronomical orientation of monuments; organised communal labour
5300–3800 BCE AHP Collapse	**Corridor dispersal**	**Knowledge in transit**	**Institutional memory**
	Northeast branch → Nile via Takarkori → HK6; Southwest branch → Tichitt (Mauritania); Fezzan survivors → Garamantes	Portable culture: cattle cult, S-twist textiles, blue-green stone beads; Canopus orientation memory preserved	Oral tradition + priestly lineage; material markers carried along corridor; no fixed architecture — mobile knowledge. Primary pastoral community established throughout Nile Valley by c. 5000

Period / Phase	WHO (People & Institution)	WHAT They Built	HOW / Key Innovation
			BCE (Wengrow et al. 2014)
3800–3100 BCE Shemsu Hor at HK6	**Corridor population dominant at Hierakonpolis**	**Hierakonpolis complex**	**Written annals begin**
	Material markers: dung fuel, *Balanites*, wild bull (aurochs) burials, sheep horn modification; elite HK6 cemetery; regional craniometric heterogeneity across the period (Zakrzewski 2007)	HK6 elite burials with exotic goods (elephant, aurochs, baboons); animal sacrifice traditions; proto-palatial structures	Leather roll of architectural plans later cited at Dendera (Dümichen 1865); Bat cow goddess → Hathor theology forming
3100 BCE Unification	**Shemsu Hor institutionalised**	**State formation**	**Knowledge exists; state capacity does not**
	Listed as category in Turin Canon; become ancestral priesthood of Horus (Frankfort 1978, Chapter 7); archives at Memphis and Heliopolis	Mastaba tombs at Saqqara; bureaucracy developing; proto-step structure documented inside Mastaba 3808 (Emery 1958)	Plans in archives, not yet executed. The 500-year gap is not a knowledge gap — it is a capacity gap. Craniometric evidence sets the Early Dynastic sample (c. 2900 BCE) apart: it is significantly distant from every other pooled period group and from every single-cemetery sample, and is described as morphologically distinct relative to the other temporal groups on account of its long broad vaults and broad faces (Zakrzewski 2007: 506–508). The Badarian is distinct on the same tests, so the Early Dynastic is not the single most distinct sample in the series; what the data support is a marked morphological shift coinciding with state formation. Kemp,

Period / Phase	WHO (People & Institution)	WHAT They Built	HOW / Key Innovation
			reproducing Zakrzewski's own plot, cautions that "the wish for clear distinctions in skull morphology by period or by region is something of an illusory goal" (Kemp 2018: 48, Fig. 1.12). Zakrzewski's own conclusion is that the process was mainly indigenous but may have occurred alongside in-migration to the Abydos region, particularly during the Early Dynastic and Old Kingdom — the interval this model places between Shemsu Hor integration and the MSP program.
c. 2670 BCE 3rd Dynasty Djoser	**Djoser + Imhotep**	**Step Pyramid, Saqqara**	**Stone replaces mudbrick**
	Imhotep: first named architect in history; drawing on Shemsu Hor archives; lector priests as institutional bridge	6 steps, 62.5 m; first stone pyramid; full enclosure complex; corbelled ceiling appears here without local precedent	Small blocks (<1 ton); stepped form encodes stairway theology; corbelled ceiling imported from existing knowledge base
c. 2613–2590 BCE PHASE ZERO Provincial Pyramids	**Huni (3rd Dyn.) and/or Sneferu (4th Dyn.)**	**Pyramids with NO burial chambers**	**Pyramid as cultic territorial marker**
	Seven provincial pyramids across Upper Egypt; el-Kula placed at Nekhen (Hierakonpolis) — 6 km from HK6	Identical dimensions: ~18.4 m base, 3 steps; built from single shared plan; food offering installations (Edfu); all abandoned during Khufu's reign (Marouard 2014)	Oriented to Meskhetyu (Bull's Foreleg constellation) — the celestial expression of the bull cult documented at HK6 (wild bull burials, sheep horn modification, ceremonial adzes). Belmonte et al. (2005): el-Kula oriented at 316°, δ* = 66.75°, toward

Period / Phase	WHO (People & Institution)	WHAT They Built	HOW / Key Innovation
			circumpolar Meskhetyu asterism. The marking precedes the monument.
c. 2613–2580 BCE Sneferu R&D (~33 years; the Turin Canon's 24 years is generally treated as an undercount — its 23 years for Khufu is directly contradicted by the Merer diary — though the true range remains contested: Ciavatti 2022)	**Sneferu + Neferma'at (son/vizier)**	**Three experiments: Meidum → Bent → Red**	**From archive to stone**
	First king with both knowledge and state resources; Prince Kanefer architect at Dahshur	Meidum: corbelled ceiling perfected; outer casing collapsed (compounding structural errors: the outer extension was founded on sand, not bedrock like the inner core; the inner step platforms were polished and sloped outward rather than horizontal, directing loads outward — possibly triggered by rainfall loading during construction). The date of the failure is disputed: Lauer (1976) argued that no collapse	Lesson 1 — anchor to bedrock, not sand. Lesson 2 — 55° is unstable. Lesson 3 — 43° works. Blocks: 2–5 tons. Bent Pyramid satellite corridor is direct precursor to Grand Gallery.

Period / Phase	WHO (People & Institution)	WHAT They Built	HOW / Key Innovation
		occurred during Sneferu's reign, and a post-Old Kingdom failure remains the alternative reading. Bent: 55°→43° mid-build; first full complex. Red: first successful true pyramid; template for Giza	
c. 2580–2540 BCE Khufu The Culmination (~40 years, after Schneider 2002; securely attested to at least regnal year 26 or 27, the latest known regnal year of Khufu on the excavators' own statement)	**Khufu inherits everything**	**Great Pyramid — full cosmological grammar**	**Scale leap: 147 m; granite from Aswan**
	Father's architects, workforce, lessons; abandons all provincial pyramid program; concentrates all state resources at Giza	Tripartite interior: Nun (below base) → Earth (Queen's Chamber) → Stars (King's Chamber); water integration (Khufu Branch canal); four stellar shafts whose targets are identified as Sirius, Orion, Thuban and Kochab, the last the least secure (Badawy 1964; Trimble 1964)	Blocks up to 80 tons; granite beams of the King's Chamber ceiling; Wadi el-Jarf papyri (contemporary logistics record); Khnum theological encoding; Khufu Branch canal makes pyramid rise from Nun
c. 2532–2477 BCE Khafre + Menkaure (dates shifted	**Grammar maintained, scale reduced**	**Giza complex completed**	**5th Dynasty: Ra cult rises**

Period / Phase	WHO (People & Institution)	WHAT They Built	HOW / Key Innovation
to follow long-Khufu chronology; absolute dates remain approximate)			
	Khafre returns to Bent Pyramid angle (53°); retains apex casing. Menkaure: granite base — new material, smaller scale	Three causeways at 270°, 271°, 276° (Nell & Ruggles 2014)	Shemsu Hor priesthood loses political primacy; knowledge preserved in archives (Cairo Leather Roll, Edfu library; Corridor III, Levy 2026c); pyramids diminish in scale and precision thereafter.

8. The Diaspora: One Lineage, Many Stones

The timeline traced the corridor branch — the populations that walked northeast from the dying Sahara toward the Nile, carrying the astronomical and cattle-cult traditions that would encode Meskhetyu at el-Kula and culminate at Giza. But that corridor was not the only path out of the Green Sahara.

If the Level 3 transmission hypothesis is correct, the "Cattle + Stone + Stars" template carried by the ancestral Saharan pastoralists should appear wherever their dispersal reached — not just in the Nile Valley. This section surveys five sibling branches of that dispersal: the Atlantic coast, the Fezzan, the Sahel, the Eastern Desert, and the Lake Turkana basin. None transmitted anything to Egypt. They are not ancestors of the pyramid tradition. They are independent expressions of the same ancestral grammar, documented in peer-reviewed archaeology and archaeoastronomical measurement. They do not prove the corridor hypothesis. They are what the hypothesis would predict. The excavators of Nabta Playa themselves note that the ceremonial installations at Nabta "are not alone in the South-Western Desert" and that recent discoveries at Bargat El-Shab and Gebel Ramlah reveal "various small-scale sacred installations" across the broader region (Schild et al. 2025: 21), consistent with the model's expectation that monumental ritual traditions were distributed across multiple Saharan localities.

As the Eastern Sahara desiccated after 5300 BCE (Kuper and Kröpelin 2006), the ancestral pastoralist population — the same Takarkori lineage documented by Salem et al. (2025) — fractured along multiple trajectories. One branch walked northeast toward the Nile. Another moved east into the Rift Valley. Another moved south into the Sahel. Another stayed in place, adapting to the drying Fezzan. Others dispersed across the Maghreb and the Atlantic coast, leaving stone monuments that still stand.

The purpose of this section is not to argue for direct transmission from any of these regions to Egypt. These sibling branches did not transmit the pyramid tradition to the Nile. What they built — independently, at different scales, across different millennia — provides a test of internal consistency for the broader model. If the ancestral Saharan pastoralists carried a shared cultural template — cattle cosmology, astronomical orientation, monumental construction —

then other branches of the same dispersal should express that template in forms adapted to their own environments. The "Cattle + Stone + Stars" package should appear not as identical architecture, but as the same ancestral grammar expressed under different conditions.

The diaspora is not proof of the corridor hypothesis. It is the pattern the hypothesis would predict.

The Western Anchor: Atlantic Dry-Stone Monuments

On the Atlantic coast of the Sahara — the same region as the Richat Structure — archaeologists have documented over 200 prehistoric dry-stone funerary monuments. This is the largest sample ever studied in the region, and the analysis was led by the same Belmonte who measured the Egyptian MSPs. These monuments show "clear orientation patterns similar to trends observed in other areas of North Africa and the Mediterranean," fitting "the visibility of particular celestial objects." The authors argue that these monuments "create sacred landscapes and house the memory of millennia of occupation." (Rodríguez-Antón et al. 2023)

But the western Sahara holds more than stone alignments. The same landscape preserves rock art and portable sculpture that Caldwell (2013) argues shares a specific symbolic vocabulary with Egypt: falcon imagery (Horus), rams wearing discs between their horns (a direct parallel to Khnum and Amun), and grinding platforms carved with inwardly spiralled snakes (Mehen, the coiled serpent who protects Ra on his night journey). These motifs appear on everyday domestic objects — grinding platforms, not temple walls — suggesting they were already embedded in pastoralist material culture before the Nile Valley state formed.

Caldwell interprets these motifs as possible precursors to later Egyptian iconography, and weighs the probability of an eastward displacement around 4000 BCE. He published this argument in 2013, twelve years before the Takarkori genome confirmed that a North African pastoralist population existed in the corridor during the relevant window. The western Sahara is not merely a sibling branch of the diaspora. It is the source region, and these visual parallels are consistent with the hypothesis that the symbols that would later appear in the Nile Valley had deep Saharan roots.

The Central Stay-Behind: Garamantes

In the Libyan Fezzan — the same landscape that produced the Takarkori genome — the Garamantes (c. 500 BCE–500 CE) built a civilisation around the same ancestral core. Salem et al. (2025) document the genome-wide data from the ancestral lineage from which the Garamantes descended — a deeply isolated North African population closely related to 15,000-year-old foragers from Taforalt (Morocco) — confirming that this lineage was not derived from sub-Saharan populations.

The Garamantes built mudbrick tomb complexes throughout the Wadi el-Ajal: some eighty at the necropolis of Kharaig alone. They are recognized in the archaeological literature as an "early state," contemporary with the Roman Empire, with "extensive links" north and south (Gatto et al. 2019; Mattingly et al. 2019).

Belmonte, Esteban, Perera Betancort and Marrero (2002) measured luni-solar orientation patterns in Garamantian tombs — the same Belmonte who measured the Egyptian MSPs. He did not connect the two datasets, but the parallel is striking: a Saharan population building monumental funerary architecture oriented to celestial events. The Garamantes maintained the cattle cult that originated in the Green Sahara, evidenced by pastoral rock art throughout the Fezzan — Wadi Mathendous, the Acacus, Wadi al-Baqar — depicting cattle herding, milking,

and ritual cattle depictions, including cattle depictions with ritual significance that directly parallel Egyptian cattle symbolism (Le Quellec 2011). The grammar — celestial orientation, cattle cult, monumental construction — persisted in the Fezzan while the branch that walked east developed the same template into the pyramid tradition. The same foggaras that sustained the Garamantes later connected the Fezzan to the Nile via the Kharga and Dakhla oases, maintaining the corridor as an active trade route for millennia.

The Southern Branch: Tichitt and the Sahelian Dry-Stone Tradition

In southeastern Mauritania, the Tichitt culture (c. 1900–300 BCE; McIntosh, Casanova & Gauthier 2026) built the oldest known stone settlements in sub-Saharan Africa. High-precision AMS radiocarbon dates from re-examined 1968 excavation materials place the Classic phase of dry-stone compounds, granary pillars, and multi-family enclosures between 1500 and 1000 cal. BCE, with cattle, sheep, and goat pastoralism documented throughout (McIntosh, Casanova & Gauthier 2026). Organic residue analysis has confirmed ruminant dairy processing in Tichitt pottery, extending the evidence for transmitted pastoralist dairying practices across the Saharan dispersal zone.

The restudy of Munson's (1971) original pottery collections reveals that paste recipes using local clays and wild-grass temper remained consistent across the entire 1,500-year sequence, even as vessel forms and decoration evolved through three distinct phases — a persistence of technical tradition alongside stylistic change that is precisely what the "Cattle + Stone + Stars" model predicts (McIntosh et al. 2026). Domesticated pearl millet — one of Africa's earliest independent domestications — appears throughout the sequence.

Tichitt is now confirmed as younger than the Egyptian provincial pyramids by approximately 700 years — too late to be a source, confirming its status as a sibling branch expressing the same ancestral grammar in an independent architectural trajectory, moving south rather than northeast.

The rock art of Dhar Tichitt reinforces the cattle-centric symbolic core. Detailed bovine herds with anatomic precision. Prominent bulls, interpreted as carrying ritual and wealth significance. Oxen-drawn carts. Herding narratives. These scenes parallel the Tassili n'Ajjer pastoral art and the bull symbolism at HK6 and Nabta Playa.

The architectural parallel between Tichitt and the Garamantes is not speculative. Both built dry-stone oval compounds with multi-family units, storage areas, and internal organisation that distinguishes them from contemporary Mediterranean or Nile Valley domestic architecture. The chronological priority of Tichitt has been taken to suggest it may have played some part in shaping the later tradition — not as direct transmission, but as a shared ancestral template reconceptualised across space and time. The Tichitt tradition is independently documented in Cambridge University Press publications as one of sub-Saharan Africa's earliest complex societies (Sterry & Mattingly 2020; Barker & Goucher 2015).

The Eastern Desert Corridor: Atbai Enclosure Burials

Between the Nile Valley and the Red Sea, the Atbai Desert preserves a newly documented monumental tradition that extends the Saharan pastoralist pattern eastward to the Eritrean borderlands. Remote sensing surveys have identified 280 circular stone enclosure burials (Atbai Enclosure Burials, or AEBs) distributed across the entire Atbai Desert from Upper Egypt (24.32° N) to Eritrea (16.69° N), with 260 of these discovered via satellite imagery since 2022 (Cooper et al. 2026). Radiocarbon-dated to approximately 4500–2500 BCE, the AEB tradition is coeval

with the termination of the African Humid Period and is explicitly described by its authors as "a local manifestation of common Saharan prehistoric burial practice" (Cooper et al. 2026: 1).

The excavated examples — at Wadi Khashab, Wadi el-Ku, and Bir Asele — all contained cattle remains alongside human internments, and the internal organization shows a pattern of a focal human burial (often in the northwest) surrounded by secondary human and animal graves. This arrangement matches the hierarchical pastoralist burial pattern documented at Hierakonpolis HK6 and at the earlier Nabta Playa complex (c. 5500 BCE), which the authors identify as the earliest known example of cattle-centred funerary behaviour in northeastern Africa. The AEB tradition thus forms the eastern extension of the same "Cattle + Stone + Stars" template: monumental stone architecture oriented within the landscape, cattle ritual as the central funerary element, and construction timed to the environmental pressures of the drying Sahara. Its geographic position — in the desert between the Nile and the Red Sea, with rare Nile Valley examples at Armant and Aswan showing "entanglement of desert and Nilotic burial traditions at the end of the fourth millennium BCE" (Cooper et al. 2026: 7) — maps precisely the contact zone where pastoralist populations integrating into the Nile Valley would have traversed.

The Eastern Branch: Lake Turkana Pillar Sites

Five thousand years ago, as the African Humid Period ended and Lake Turkana's shoreline receded, the region's first herders built something eastern Africa had never seen. The Lothagam North Pillar Site (c. 5000–4300 BP) is a megalithic platform mortuary — 119.5 square metres, ringed by stone pillars, containing an estimated minimum of 580 individuals. Hildebrand and colleagues draw from it a conclusion directly relevant to the present argument: that monumentality may arise among dispersed, mobile groups without strong hierarchy, and that in sub-Saharan Africa it was dispersed pastoralists who pioneered monumental construction. Lothagam North, they note, is not demonstrably linked to the emergence of hierarchy at all. It is the earliest and most massive monumental site in eastern Africa (Hildebrand et al. 2018).

The excavators' language is striking: Lothagam North was built by "eastern Africa's earliest herders as the African Humid Period ended and Lake Turkana's shoreline receded, at a time when mobility and uncertainty would have been paramount." They did not build it for a king. The mortuary cavity shows no evidence of hierarchy — no elite burials, no differential grave goods. Instead, the monumentality served as "an important unifying force for eastern Africa's first herders, bringing together communities at a time when profound landscape changes and the socioeconomic uncertainties of a moving pastoral frontier could have otherwise torn them apart" (Hildebrand et al. 2018).

The Lothagam North site provides a structural parallel to Phase Zero: a monumental response to climate-driven landscape change by mobile pastoralists, using astronomical orientation to create a unifying social structure. The specific forms differ — a communal mortuary platform versus territorial-cultic markers — but both represent the same underlying pattern: pastoralist populations responding to the stresses of the African Humid Period termination by building large-scale, astronomically oriented stone monuments.

A second Turkana-basin site carries the pattern further. At Namoratunga the pillars are basalt and have been argued to align on seven star systems: Triangulum, Pleiades, Bellatrix, Aldebaran, Central Orion, Saiph and Sirius (Lynch & Robbins 1978). A statistical analysis by Doyle and Wilcox found that the probability of obtaining twenty-five or more alignments with these seven star positions by chance is 0.43%, which they took to indicate that the pillars were built for astronomical observation (Doyle & Wilcox 1986). Two qualifications belong with the

claim. Namoratunga dates to approximately 300 BCE, some two millennia after the Minor Step Pyramids, so it stands as evidence for the persistence of the practice in the eastern branch rather than for its origin; and the astronomical interpretation has been contested (Soper 1982), with the identification of nineteen aligned pillars and the significance of the correlations both questioned. Taken with that reservation, it indicates that the association between monumental stone and stellar observation remained active in the Turkana basin long after the African Humid Period had ended.

The eastern branch reinforces what the western anchor suggests: the diaspora carried not just cattle and stone, but a practice of monumental communal burial at a scale unmatched in the region.

What the Diaspora Reveals

The diaspora is not a collection of isolated parallels. From the Atlantic dry-stone monuments and Caldwell's falcon/ram/snake iconography to the Atbai enclosure burials stretching from Upper Egypt to Eritrea and the Lake Turkana pillar sites with their statistically significant stellar alignments; from the Garamantes' mudbrick tombs and cattle-reverence engravings to the Tichitt dry-stone villages and bull-centric rock art — the same ancestral population, dispersing from the same collapsing landscape, built monumental structures oriented to the sky and encoded with the same symbolic grammar.

The specific forms differ. The scale differs. The chronology differs. But the grammar is consistent: stone (or mudbrick), cattle (or their symbolic equivalent), orientation to celestial bodies, funerary or communal ceremonial function, and iconographic echoes of the bull cult and geometric symbols that would crystallise as Meskhetyu and the Wedjat tradition in the Nile Valley.

The corridor branch produced the most architecturally sophisticated expression — the step pyramid, the true pyramid, the Great Pyramid at Giza. But that expression was not an isolated invention. It was one node in a network of monumental traditions that spanned the Sahara.

The diaspora does not prove the corridor hypothesis. The corridor hypothesis stands on the paleohydrology, the genetics, the HK6 material markers, and the Belmonte measurements. What the diaspora provides is a test of internal consistency. If the model were wrong — if the ancestral Saharan pastoralists had no shared monumental tradition, no astronomical orientation practice, no cattle-cult cosmology, no shared symbolic vocabulary — then these parallel developments across Africa would be coincidences requiring independent explanation for each.

The diffusion dynamics underlying this diaspora pattern are documented at finer resolution within the Nile Valley itself. Alcouffe et al. (2025) trace an S-shaped adoption curve for funerary innovations at Adaïma, demonstrating that the spread of new ritual forms through pastoralist-derived communities followed predictable diffusion dynamics — the same process that, at larger scale, distributed the 'Cattle + Stone + Stars' template across the Sahara.

The fact that they exist, that they share structural features across thousands of kilometres and thousands of years, and that they emerged from the same climatic trigger — this is consistent with the model's central claim: the Saharan dispersal produced monumental astronomical traditions wherever it went.

They are not proof. They are corroboration. The people who built Giza were part of a diaspora that stretched from the Atlantic to the Red Sea, from the Mediterranean to the Sahel — a

network of populations derived from the same Saharan dispersal, expressing a shared ancestral culture in monumental form.

9. The Sneferu R&D Phase: Three Pyramids as Applied Archival Knowledge

The pyramid tradition ran on two parallel tracks simultaneously, and Djoser belongs to Track 1 — not to Phase Zero. Track 1 — Construction and engineering: Djoser's Step Pyramid (c. 2670 BCE) established that the form could be built at monumental scale in cut stone: 62.5 metres tall, with corbelled elements in its underground galleries and a complex subterranean chamber network extending several kilometres. Its orientation, measured from Lauer's architectural survey at approximately 3° from true north (Lauer 1960: 99; attested in Romer 2007: 279), records the first attempt at cardinal alignment using circumpolar stars. The direction of that deviation is reported differently in the literature: east of north in Lauer and Romer, west of north in Belmonte (2001: S19, note 39). Belmonte (2001) has proposed that Meskhetyu — the same circumpolar constellation targeted by the MSPs — was the reference asterism for Old Kingdom pyramid orientation from Djoser onward (Belmonte 2001; Belmonte & Lull 2023: 377). His proposal is specific about method, and the detail matters here. Spence (2000) had argued that the Egyptians obtained true north by watching two stars on opposite sides of the pole reach a common vertical, using Kochab in Ursa Minor with Mizar in Ursa Major. Belmonte proposed instead a pair drawn from within a single constellation, Megrez and Phecda, both in Meskhetyu, with the pole recovered by extending the line joining them rather than by bisecting it. The idea is older than either: Pólak had already argued in 1952 that in Khufu's time the simultaneous lower culmination of Megrez and Phecda would have given an excellent indicator of north, and Belmonte's proposal revives and develops it (Lull 2008). Lull himself, however, doubts that any single technique accounts for the whole record: on his reading the spread of orientation errors across the larger group of pyramids cannot be explained by uniform application of one method, and secondary alignment from an already-oriented monument or solar observation may account for some cases (Lull 2008: 91). He also notes that no text explicitly describing the stellar orientation of temples or tombs survives from most of Egyptian history; the Edfu and Dendera inscriptions discussed below are very late. The continuity proposed here is therefore a continuity of one attested method among several possible ones, not a claim that the same procedure was used everywhere. Rawlins and Pickering (2001) subsequently identified a computational error in Spence's derivation, and the corrected result points more firmly toward a different pair; on Belmonte's stars the commencement of the Great Pyramid falls near 2550 BCE rather than Spence's 2480 BCE. Two consequences follow for the present argument. The stars Belmonte identifies for the orientation of the large pyramids are the same pair he identifies at Seila, so the Seila alignment is not an isolated observation but the earliest instance of the method later used at Giza. And the reference body is Meskhetyu itself, not a star of Ursa Minor, which places the constellation this paper tracks at the centre of the orientation tradition rather than adjacent to it. Belmonte has further connected the northern orientation of the pyramids by Meskhetyu's meridian transit to the name of the Lower Egyptian province whose capital was Letopolis, the Bull's Foreleg — an Egyptian administrative unit carrying the constellation's name. At Saqqara, the result was approximately 3° from north. By Khufu, the same orientation tradition achieved 3′ from north — a sixtyfold improvement in precision across five pyramid projects spanning two dynasties. Track 2 — Territorial and institutional: The MSPs, built after Djoser proved the form was achievable in cut stone, are 35 cubits square at the base and stood between about 4 and 8.25 metres high — Radwan's figures, as reported by Bárta (2005: 181) — not because larger was beyond reach, but because their function required no more. A territorial and cultic marker at a provincial Shemsu Hor site does not need to rise 62.5 metres. Djoser's 62.5-metre pyramid sat inside a 15-hectare mortuary precinct with 6 kilometres of underground galleries, ceremonial courts, and a complete ritual complex. The MSPs are the pyramid form detached from all of

that: just the marker, at appropriate provincial scale. Scale is proportionate to purpose. Both tracks targeted the same constellation throughout. The construction track improved in precision; the territorial track distributed the symbol. Seila MSP is the convergence point of the two tracks: the only MSP oriented to true cardinal north (0°), the one Sneferu personally claimed on a stela, and — in the construction sequence — the earliest of Sneferu's four pyramid projects, preceding his three large pyramids at Meidum and Dahshur. One structure, two roles: the last Phase Zero territorial marker and the first experiment in the engineering track that would culminate 147 metres above the Giza plateau. If Phase Zero established the pyramid as a territorial and astronomical marker at the Shemsu Hor sites, Sneferu's three large pyramids represent the first attempt to integrate that symbolic form with a burial function at scale. The sequence — Meidum (outer casing collapsed), Bent (angle corrected mid-build), Red (first stable true pyramid) — is not a story of invention but of application and correction.

The corbelled burial chamber within the pyramid body, which appears at Meidum without any local developmental sequence in above-ground Egyptian masonry, is the clearest architectural evidence of imported knowledge. It appears fully formed at Meidum, is perfected in the Red Pyramid's three-chamber sequence, and is deployed masterfully in the Grand Gallery of the Great Pyramid. No intermediate steps in stone corbelling exist between its first appearance and its confident use, though mudbrick corbelling appears earlier in some mastaba tombs — a material transition consistent with the broader shift from mudbrick to stone documented across the Early Dynastic and Old Kingdom periods. The technique was not developed at Meidum — it was tested there.

Belmonte and Magli (2015) demonstrate that the Bent and Red Pyramids at Dahshur were conceived as a unitary sacred landscape from the outset — not two sequential projects, the second generated by the failure of the first. This is consistent with a builder who had access to archival plans and was implementing a coherent cosmological vision across multiple structures simultaneously.

The critical architectural comparison is Sneferu's three pyramids versus Khufu's one. Sneferu distributed his legacy across three sites. Khufu concentrated everything at a single location and added specific innovations — stellar shafts, the Grand Gallery, and full water integration via the Khufu Branch canal — to the architectural grammar that Sneferu's three pyramids had developed and refined. The tripartite interior and corbelled ceilings that appear in Sneferu's pyramids were scaled to their fullest expression under Khufu.

10. Khufu's Centralization: The End of Phase Zero

The Edfu excavation established that the provincial pyramid there received food offerings until Khufu's reign, at which point offerings ceased and the pyramid was abandoned — less than 50 years after construction (Marouard & Papazian 2012; Marouard 2014). The El-Ghonemiya excavation has not received a final monograph: fieldwork ceased in 2012, and the published record consists of preliminary field reports, which are the standard evidentiary basis for this site. Marouard's direct statement: Khufu "focused all the resources on building the Great Pyramid at Giza."

This moment of centralization is the hinge of the entire argument — not as a beginning from nothing, but as the concentration of a building tradition that Sneferu's three pyramids had already proven at scale. The provincial pyramid program — the visible, distributed expression of the Shemsu Hor tradition at its own sites — was explicitly discontinued when Khufu moved the tradition into a single monument of unprecedented scale. The archaeological signature of that discontinuation is visible at Sinki, the MSP at Abydos — the oldest royal necropolis in Egypt, the

site of the 1st and 2nd Dynasty kings. Sinki was found with its mud-brick construction ramps still *in situ*, abandoned at the second step, pavement and outer facing never applied. Of all the sites in the MSP program, Abydos was the one most charged with royal ancestral significance. Its pyramid was left unfinished, and no one returned to complete it. The program did not wind down gradually; it stopped. The seven territorial markers were superseded by one cosmological universe.

The Wadi el-Jarf papyri (c. 2560 BCE) record the logistics of limestone transport to Giza during Khufu's 26th or 27th regnal year. They are administrative records — shift logs, not cosmological documents. The cosmological knowledge was not in those papyri. If the transmission model is correct, it resided in the Shemsu Hor archives — the written annals cited by Thutmose I on the Tombos Stele (Sethe, Urk. IV, 82–87) and the leather roll of architectural plans cited by the Dendera builders (Dümichen 1865; Mariette 1870–75) — whose contents are known only from later citations. Khufu's workforce moved stones. His institutional inheritance told him what shape to give them and what they meant.

The abandonment of the provincial pyramid program raises a question the paper must address directly: was Khufu fulfilling the Shemsu Hor tradition, or replacing it? The most defensible answer is that he did both simultaneously — and that this is not a contradiction. Centralization is what fulfillment looks like when capacity finally matches ambition. The distributed provincial markers were the tradition expressing itself at the scale available for five centuries. Khufu concentrated that expression into a single monument of such scale that the distributed network became redundant. The cosmological grammar did not change; the vessel changed. The bull still pointed north. The circumpolar asterism still marked the eternal afterlife of the king. The astronomical alignment that el-Kula encoded in a marker a few metres high was now encoded at 146 metres, with the same orientation logic applied to the entire plateau.

The 5th Dynasty evidence supports this reading rather than contradicting it. When Khufu's successors built solar temples and Unas inscribed the first Pyramid Texts on his burial chamber walls, the priestly tradition was reasserting distributed institutional authority — not recovering from suppression, but finding new architectural form after the 4th Dynasty's monopoly on monumental scale had passed. The Shemsu Hor tradition, in this reading, was never extinguished. It was promoted under Khufu, distributed again under the 5th Dynasty, and eventually encoded in the Pyramid Texts that would survive to document it. The MSP abandonment is not a rupture in the tradition. It is the moment the tradition outgrew its provincial containers.

The Political Geography of Abandonment

What Sinki's unfinished ramps most plausibly document is not just the timing of centralization, but its political geography. Abydos was the royal burial ground of the Thinite line — the rival polity that unified Egypt but was not the original Shemsu Hor capital. Hierakonpolis (Nekhen) was the Shemsu Hor seat (Frankfort 1978; Levy 2026c, Paper III). When Khufu centralized all resources at Giza, the MSP program was abandoned across all seven sites. But Sinki was left more visibly unfinished than any other MSP — ramps still *in situ*, pavement never applied, outer facing never added.

The contrast between Seila and Sinki maps this political geography directly.

Table 5: Divergent Completion States — Seila vs. Sinki

Feature	Seila (Fayum)	Sinki (Abydos)	Interpretation
Orientation	0° True North (cardinal)	318.75° quarter-cardinal (non-cardinal)	Seila prototypes the cardinal alignment required for Giza
Builder	Sneferu (confirmed by stela)	Unknown (programmatic attribution only)	Sneferu personally claims Seila; Abydos is unattributed
Completion	Finished — casing and pavement applied	Unfinished — ramps in situ, no casing, no pavement	Seila receives resources; Sinki is abandoned mid-construction
Proximity to Giza	Northeastern edge of Faiyum, near Memphite region	Southern Upper Egypt, distant from Memphite region	Seila is closer to the new center of power
Political Geography	Near the emerging Memphite power base	Thinite ancestral burial ground (rival tradition)	Seila is "new territory"; Abydos is "old (rival) territory"

All declinations here are computed for 2570 BCE, the epoch Belmonte and colleagues adopt throughout for coherence. Belmonte and Magli (2015: n. 4) select 2575 BCE for Sneferu's accession, which they describe as close to the low chronology of Hornung, Krauss and Warburton (2006: 490–491), whose table gives Sneferu 2543–2510 BCE with a margin of up to 25 years earlier (2568–2535 BCE); as other published values they list 2613–2589 BCE (Shaw 2000), 2639/2604–2589/2554 BCE (von Beckerath 1997) and a very low 2520–2470 BCE (Dodson and Hilton 2004). Sources: Belmonte, Shaltout & Fekri (2005) for orientations; Belmonte et al. (2005: 7) for Seila stela; Maragioglio & Rinaldi (1963) for Sinki's unfinished state; Ćwiek (1998) for programmatic attribution.

The distinction is not merely chronological — both pyramids were built within the same late 3rd/early 4th Dynasty window. The distinction is political. Seila marked the birth of cardinal alignment, the geometric language of Giza, and was therefore claimed by Sneferu and completed. Sinki marked the old provincial grammar — the quarter-cardinal orientation shared with el-Kula and El Ghoneimiya — at the Thinite ancestral burial ground, and was therefore left unfinished when Khufu centralized all resources at Giza.

This suggests that the tradition's ideological center (Hierakonpolis) received priority even in abandonment, while the rival ancestral site at Abydos was left as a ruin. Alternative explanations — seasonal work stoppage or unrelated workforce shortages — cannot entirely rule out the coincidence of abandonment across multiple MSP sites during Khufu's reign, but the specific incompleteness of Sinki favours political prioritization as the primary cause. This is not the signature of a tradition being replaced. It is the signature of a tradition being staked on a single, monumental act — with the political geography of ancestral memory inscribed in which provincial markers received finishing and which were left bare.

11. The 500-Year Gap: Knowledge or Capacity?

The most common objection to the transmission argument has been the apparent gap between the Shemsu Hor period (3800–3100 BCE) and the Great Pyramid (c. 2580 BCE). The broader astronomical interval — approximately 800 years between Nabta Playa's terminal phase and el-Kula's construction — has been addressed in Section 5 (Belmonte's Field Measurements), which documented that the Fezzan corridor contains ceremonial architecture and ritual iconography directly within this window, and that the span is comparable to gaps conventional Egyptology bridges through oral tradition and institutional memory. This section addresses the distinct question of the 500-year gap between the Shemsu Hor integration period and the Giza culmination.

Phase Zero reframes the objection. The gap is real, but the question is what kind of gap it represents. The knowledge was not waiting in an archive for five centuries. It was being expressed continuously in stone — first in the subterranean tumuli of Abydos (Engel 2008; Dynasty 1, from c. 3100 BCE; Dee et al. 2013), then in the provincial pyramids placed at the Shemsu Hor's own integration sites, then in Sneferu's three experimental structures, and finally in Khufu's Great Pyramid. The tradition was never dormant. It was scaling.

Significantly, Saharan pastoralists remained present at Nabta Playa long after the megaliths were built. The megalith builders belong to the Final Neolithic (c. 4600–3600 BCE; Schild et al. 2025: Table 3.3), but OSL ages on the sediments beneath the fallen stelae link their toppling to C-Group pastoralists at about 2500–2160 BCE (Schild et al. 2025: 20), and the C-Group phase itself is dated c. 2400–1450 BCE (Schild et al. 2025: Table 3.3). This evidence concerns the pastoralists' presence and their treatment of the older monuments; it does not show that megalithic ceremony continued, and the 2500–2160 BCE interval falls after the Phase Zero provincial pyramid programme (c. 2613–2590 BCE), in the middle and later Old Kingdom. It does show that Saharan pastoralist populations were still in the Nabta region while the Old Kingdom state was building its pyramids, so the gap between the two traditions is narrower than a simple terminal date for the megaliths would suggest.

Nor is the duration of the gap exceptional when compared to other complex cultural systems developing during the same centuries. Kahl (2001) has argued that hieroglyphic writing itself required more than 400 years to progress from an early notational system, attested on labels from Tomb U-j (c. 3320–3150 BCE), into a functionally complete script during the reign of Den (c. 2925 BCE; Dee et al. 2013). The same corpus shows contraction as well as development: the first two dynasties produced a repertoire of over a thousand signs, more than is known for any later period down to Ptolemaic times, and many of those signs had fallen out of use before the Old Kingdom began. Capacity in a documented Egyptian system therefore both accumulated and was lost across precisely the interval at issue here. Kahl notes further refinements continuing into the 3rd Dynasty. If the most fundamental tool of state administration required an extended period of institutional development, it is consistent with the model proposed here that a specialized body of astronomical and architectural knowledge would require a comparable period of incubation within state institutions before reaching monumental expression. This framework of long-term conceptual continuity is endorsed by Belmonte and Lull in their 2023 synthesis of Egyptian astronomy, who treat the persistence of astronomical alignment traditions across millennia as a foundational principle for understanding Egyptian sacred architecture (Belmonte & Lull 2023, p. 402).

The persistence of complex administrative structures across this period is documented not only in the development of writing but in the continuity of the titulary system itself. Fischer (1996) has documented a late Old Kingdom stela (Berlin 7779, 8th Dynasty) on which the title 'Overseer of

the Two Treasuries' appears with a full complement of subordinate fiscal offices, indicating that specialized bureaucratic structures persisted even after the centralization of the pyramid age had passed. While this evidence postdates the Giza pyramids by several centuries, it demonstrates that complex administrative knowledge could survive periods of political decentralization — consistent with the broader model of institutional continuity proposed here, in which the capacity to organize large-scale projects was not lost but fluctuated with the degree of state centralization.

The 500-year gap is the time required to develop the following:

- State quarrying infrastructure capable of moving 80-ton granite beams from Aswan to Giza.
- Labour organization sufficient to sustain a professional workforce across decades of construction — whether concentrated within a single reign or spanning the Sneferu–Khufu transition, the project demanded sustained state capacity at a scale not previously attempted.
- Hydrological engineering capable of channelling the Khufu Branch of the Nile to the pyramid's base — making the pyramid literally rise from the waters of Nun.
- Large-scale water management — already attempted, if not yet mastered, as shown by the early Old Kingdom Sadd el-Kafara dam, designed to impound approximately 570,000 m^3 of floodwater (Wong 2021, citing Arnold 1991). The dam is the clearest single illustration of the distinction argued here. Its scale and construction indicate systematic rather than experimental work, and modern assessment holds that it would have withstood the floods reasonably to be expected had it been completed. It was not completed: lacking a spillway, it was overtopped and destroyed by a flood after some ten to twelve years of construction, and the project was abandoned and never resumed. The knowledge was present; the capacity to finish and protect a work of that size was not.
- Political centralization sufficient for a single king to concentrate all of these resources at a single site.

Comparable capacities elsewhere plausibly required extended periods of state consolidation, though no systematic cross-cultural comparison is offered here and none is claimed. Climatic instability may also have contributed to the interval. Hassan (2007) has argued that a severe low-Nile episode c. 2200–2150 BCE contributed to the collapse of Old Kingdom central authority, demonstrating the vulnerability of the Egyptian state to environmental stress. If such disruption could destabilize a mature state, earlier Holocene climatic fluctuations may have periodically interrupted the institutional continuity required for large-scale monumental projects during the Predynastic and Early Dynastic periods, contributing to the interval between the earliest evidence of astronomical knowledge at Nabta Playa and its monumental encoding in the MSP program. The MSPs were not a preliminary sketch for Giza. They were the form the pyramid tradition took when state capacity was distributed across provincial centers rather than concentrated at a single site. Sneferu's three pyramids then represent the experimental transition — testing whether the step-pyramid form could be scaled to burial-monument size — and Khufu's centralization represents the moment capacity finally matched the cosmological ambition that Phase Zero had encoded in stone at a few metres' height.

The interval proposed here is not exceptional in the Egyptian context. Alcouffe et al. (2025) document a comparable gap between local ritual practice and textual codification at Adaïma,

where a 'breaking of the red pots' ritual in a Third Dynasty burial appears to anticipate its documentation in the Fifth Dynasty Pyramid Texts by approximately 350 years. As the authors note, 'it is important to distinguish between the date of inscription and the earlier stages of formulation and transmission' (Alcouffe et al. 2025, p. 27). The same principle applies to the Meskhetyu tradition: the astronomical knowledge encoded at el-Kula and later at Giza did not originate in the moment of its monumental expression. It was transmitted across centuries of institutional memory before the state acquired the capacity to render it in stone. The formalization of astronomical knowledge into state systems was already underway during this interval. The Egyptian civil calendar, dated to approximately 2782 ± 32 BCE (Alcouffe et al. 2025, citing Winand 2005), represents the state's first documented effort to systematize celestial observation for administrative and ideological purposes — a precursor to the astronomical encoding that the MSPs would perform in stone less than two centuries later.

Whether these were knowledge problems or capacity problems is ultimately an empirical question. What Phase Zero suggests is that the symbolic and astronomical tradition was continuous across the interval. The question is not whether the knowledge existed, but when the state acquired the means to express it at monumental scale.

12. Falsifiable Predictions

The argument of this paper is that the Minor Step Pyramids constitute a Phase Zero of the pyramid tradition — not tombs, but territorial and cultic markers placed at Predynastic ceremonial centres and encoding an astronomical inheritance that originated in the Saharan pastoralist world. This argument generates predictions that are specific to the MSPs, their astronomical orientations, and the material culture at the sites where they were built. Each prediction is testable using methods that already exist, against evidence that is either published or held in museum collections.

1. **Ancient DNA from the el-Kula construction period at Hierakonpolis** will show affinity with the Takarkori North African Neolithic lineage (Salem et al. 2025), consistent with the corridor population's continued presence at the site where the Meskhetyu tradition was first encoded in monumental stone. No such analysis has been published to date.

2. **Strontium and oxygen isotope analysis** of skeletal remains associated with MSP construction will show signatures inconsistent with a purely local Nile Valley origin. Suitable material exists and is identified: the excavation of Sinki recorded fourteen burials within and immediately around the pyramid remains, of which one can be connected directly with the construction (Dreyer & Swelim 1982). A bioavailable strontium baseline for the Nile Valley has since been established (Simonetti et al. 2023), and the method has already been applied to Egyptian material of comparable character in the isotope geoprovenancing of baboons from Hierakonpolis and later sites (Dominy et al. 2020). No such analysis has been published for the minor step pyramids. Falsification condition: signatures indistinguishable from the local baseline at the site concerned.

3. **Reanalysis of published Messak stelae orientation data for circumpolar targets.** The Gauthier and Gauthier (2004) survey documented azimuth orientations for 52 intact central stelae across the Messak Settafet plateau, within the ceremonial monuments radiocarbon-dated to the Middle Pastoral, c. 5200–3800 BCE (di Lernia et al. 2013). The dominant interpretation of these orientations is solar or lunar, but the published data includes outliers that do not fit either pattern. A reanalysis testing whether any statistically significant subset of stelae orientations corresponds to the contemporaneous

lower culmination of Meskhetyu — the same circumpolar tradition documented at Nabta Playa and later encoded at el-Kula — would determine whether Meskhetyu tracking was active in the Fezzan corridor during the interval between the Saharan astronomical complex and its Nile Valley architectural expression. This prediction is testable against published survey data and requires no new fieldwork. The original survey data (Gauthier & Gauthier 2004) is over 20 years old; reanalysis may be constrained by the precision of the original measurements. Falsification condition: all stelae orientations are adequately accounted for by solar or lunar models, with no statistically significant circumpolar component.

4. **Meteoritic analysis of the Hierakonpolis ceremonial adzes.** Quibell and Green (1900) documented ceremonial adzes from the Hierakonpolis Main Deposit whose shape matches the Meskhetyu asterism. Almansa-Villatoro (2019) argued that Egyptian cosmology understood the sky as an iron vault whose fragments fell to earth as meteorites and were worked into ritual objects, the material carrying the name *bjꜣ n pt*, "iron of the sky", which Egyptian texts associate with the northern celestial realm from which Meskhetyu descends. In later periods the adze employed in the Opening of the Mouth was of meteoritic iron. Whether that material association reaches back to the Main Deposit is an open question, and the prediction should be framed as a test of what these objects are rather than as an expectation of what they will prove to be. The Hierakonpolis material is Dynasty 0, roughly a millennium earlier than the oldest securely identified meteoritic iron objects in Egypt, the Gerzeh beads, and Quibell and Green's own plate list records a Main Deposit dominated by flint, stone, ivory and glaze, with copper as the only metal noted among the forty-three plates of the first volume. The expected result is therefore that the ceremonial adzes are not iron. What non-destructive X-ray fluorescence can establish is their actual composition, and every outcome is informative. If they prove to be copper, the alloy can be tested for elevated nickel. If stone or ivory, the celestial-material association demonstrably postdates the object class. A meteoritic signature, conversely, would place the sky-iron association a full millennium earlier than currently attested and would be a substantial result in its own right. Falsification condition for the stronger reading: the adzes contain no iron, which would confine Almansa-Villatoro's material argument to the periods for which it is directly attested and remove it from the Predynastic chain proposed here, leaving the shape correspondence of Section 6 to stand or fall on its own.

5. **Archaeoastronomical survey of Gilf Kebir ritual structures** for circumpolar or Meskhetyu orientations. Bárta (2014) identified the Cave of Swimmers and Cave of Beasts as containing ritual iconography directly ancestral to Pharaonic kingship — the White Crown, the Sed Festival run, the Nut-Gebe cosmology — but did not measure the orientations of the caves, the panels, or the individual figures for astronomical content. Systematic archaeoastronomical survey of these accessible sites would test whether the iconographic tradition was accompanied by deliberate astronomical orientation. The survey should target painted panel and figure orientations within the caves — human choices — rather than natural cave openings, which are geologically determined. If the White Crown figure, the Nut-Gebe composition, or the painted panels align with circumpolar north, solstice, or Meskhetyu targets, this would document active astronomical observation at a refugium site directly on the corridor between Nabta Playa and Hierakonpolis. Falsification condition: no orientations consistent with Meskhetyu or circumpolar targets are identified; panel orientations are adequately explained by topography or other non-astronomical factors.

6. **Spatial discrimination of MSP site selection.** The existing spatial correlation between MSP locations and documented Predynastic ceremonial centres (Elephantine, Hierakonpolis, Naqada, Abydos), two of them — Hierakonpolis and Abydos — carrying explicit Shemsu Hor textual associations has been established (Section 3, Location: The Shemsu Hor Sites). The falsifiable extension of this observation is: systematic survey of all Old Kingdom provincial capitals should show that MSPs are absent from sites without Predynastic elite ceremonial activity, even where those sites are comparably significant as administrative and economic centres. The test has to be framed against the economic reading specifically, since that is the form the alternative actually takes: Bárta (2005: 181) reads the monuments as indicators of major royal economic centres whose distribution tracks the principal agricultural basins, so administrative rank alone does not capture his claim. The discriminating survey is therefore of provincial capitals matched for Old Kingdom administrative rank and agricultural catchment but differing in Predynastic ceremonial activity. If such sites lack MSPs, the economic reading cannot account for the selection criteria; if MSPs are found at them, the transmission model cannot. No such systematic comparative survey has been published. The absence of MSPs in the Nile Delta — an established fact — is consistent with this prediction: the Delta had no equivalent Shemsu Hor-documented Predynastic ceremonial centres (Belmonte et al. 2005).
7. **Independent verification of el-Kula's northern horizon altitude and axis azimuths.** Belmonte et al. (2005, Table 1) record el-Kula's secondary axis at azimuth 1¼°, giving a declination of 66¾° at an angular height of 2°, and corresponding to the lower circumpolar threshold of Meskhetyu at approximately 2570 BCE. Two quantities require independent determination. The first is the azimuth of that line, which the authors measured with a compass corrected for magnetic declination at a stated precision of about half a degree; a theodolite and GPS survey would establish it to a far tighter tolerance. The second is the angular height, which in Belmonte's table is flagged as a special value — the altitude at which the target becomes observable rather than a surveyed horizon profile — and which has not been measured on site at all. Since the declination moves degree for degree with that altitude, the actual northern horizon along el-Kula's sightline is the single most consequential unmeasured quantity in this argument. A second archaeoastronomical team should report both, with uncertainties. Falsification condition: a measured azimuth inconsistent with a deliberate near-north alignment, or a surveyed horizon altitude that places the declination outside the circumpolar threshold of Meskhetyu at the construction epoch. A horizon differing from the assumed value by more than roughly half a degree would be sufficient to displace the target.

13. The Builders: What the Evidence Tells Us

When the MSP program, Sneferu's three experimental pyramids, and the full Giza project are modelled against documented constraints — Stocks' experimentally measured copper-saw cutting rates, the Hatnub rope-and-post haulage system, stratified block volumes, and Merer's delivery cadence documenting active casing in Khufu's 26th or 27th regnal year — the total accumulated active construction time across all phases falls in the range of approximately 85–110 years. The remaining ~400 years of the roughly 500-year interval were occupied by state formation, bureaucratic consolidation, and the gradual build-up of the administrative and logistical capacity required to execute a project at Giza scale. The objection treats the 500 years as silence. The evidence shows that less than a quarter of it was spent actually moving and placing stone.

Phase Zero established what was built and why; Sneferu demonstrated it could be done at scale. The question of *how* — the physical methods by which the 4th Dynasty translated cosmological grammar into 147 metres of precision-engineered stone — is the final term in the sequence. Without a plausible, evidence-constrained construction scenario, the claim that the 500-year gap represents a capacity gap rather than a knowledge gap remains an abstract assertion. This section evaluates whether such a scenario can be constructed within the constraints of the evidence.

An honest acknowledgment is required at the outset. The archaeological and textual record documents *who* built the pyramids, *what* they built, *when* they built it, and *what materials* they used. It does **not** document the precise lifting method. No surviving Egyptian text describes how blocks were raised above the lower courses. No ramp system has been excavated intact at Giza. No construction drawings have been found. No construction method has achieved consensus within the current archaeological and engineering literature.

What follows is organized in three layers. The first establishes hard constraints from documented evidence — independent of any construction model. The second derives non-negotiable requirements that any viable model must satisfy. The third tests one candidate model against those requirements, not to establish it as correct, but to demonstrate that at least one model satisfies all known constraints. If such a model exists, large-scale construction was mechanically plausible within documented 4th Dynasty capability.

Layer 1: Hard Constraints (Model-Independent)

The following constraints are established by archaeological, textual, and experimental evidence. They do not depend on any specific construction model.

Who Built It

The pyramid was not built by slaves. This is settled by archaeological evidence. The workers' village at Heit el-Ghurab, first excavated by Mark Lehner in 1988 and developed through decades of work by the Ancient Egypt Research Associates, documents a purpose-built settlement with bakeries, breweries, fish-processing facilities, and a cemetery (Lehner 1997; Hawass & Lehner 1997). Skeletal remains show healed fractures. Workers were provisioned with cattle and goats at a rate capable of feeding approximately ten thousand people per day at peak construction — a diet consistent with a valued state workforce, not forced labour. Workforce estimates range from Hawass's figure of five thousand permanent specialists and fifteen thousand rotating labourers to Lehner's twenty thousand to twenty-five thousand at peak. The number of placement teams the workforce can field simultaneously, approximately 588 at one placement per team per day — giving a sustained average of ~356 blocks per day across the full overbuild phase — derived and reconciled in Layer 3 below, assumes a workforce at the lower end of this range (~10,000), consistent with the scale of Heit el-Ghurab and the phyle structure documented in the Merer diary; a larger workforce would increase both figures proportionally. The workforce was organized into named gangs, structured through the phyle system documented from the 1st Dynasty onward and reaching its most elaborated form during the 4th Dynasty pyramid-building peak (Roth 1991; Abou Zeid, Fekri & Qandil 2021). Roth's study of the system concludes that the phyles originated in an Upper Egyptian form of social organisation datable to the Predynastic period, and that they played a larger part in the stability of the early Egyptian state than is generally recognised — an organisational continuity across the same interval this paper argues for in the cultic and astronomical material. The phyle names — *wr*, *wsd*, *nds*, and others — appear on the very tools that cut and dressed the pyramid stone: adzes, mallets, and chisels inscribed with gang affiliations and division marks. Graffiti in red

ochre inside the sealed relieving chambers above the King's Chamber — spaces never meant to be seen again — record names including "Friends of Khufu." These are not the marks of coerced labour.

The Merer Papyri

The most direct human record is the Diary of Merer (Tallet & Marouard 2014), the oldest papyrus documents found in Egypt, recovered at Wadi el-Jarf in 2013 and written during the 26th or 27th regnal year of Khufu's reign. Inspector Merer's phyle of approximately forty men — one unit of "The Escort Team of the Uraeus of Khufu Is Its Prow" — transported white limestone casing blocks from Tura to Giza by boat, completing two to three return trips every ten days: approximately two hundred blocks per month from one team. The figure is internally checkable. Vessels of the type recorded could carry a load of roughly seventy to eighty tonnes, or about thirty blocks of two to three tonnes each, so thirty blocks on each of two or three round trips in each ten-day week brackets the two hundred or so per month the papyri record. The diary also fixes the season: the surviving entries run from July to November, and the voyages could only have been made around the annual flood, when the high water made the river and canals navigable for heavily laden boats. Transport was therefore not continuous but bounded by the inundation, a constraint the phase durations set out below assume. Crucially, Merer does not describe construction onset; he captures a late-stage logistical phase already in operation. This provides an independent chronological anchor: casing delivery was still active in Khufu's 26th or 27th regnal year.

What the Stone Tells Us

The final net stone volume of the Great Pyramid as it stands today can be derived independently of any construction model. The design values are 440 royal cubits of base and a seked of 5½ palms, which fixes the height at exactly 280 cubits and the slope at 51.843° (Petrie 1883; Dash 2015). A seked of 5½ palms is a run of 5½ palms for each cubit of seven palms of rise, so the half-base stands to the height as 220 to 280 and the slope is arctan(280/220) = 51.843°. All conversions here use a royal cubit of 0.5236 m (Petrie 1883; Zapassky et al. 2012), giving a base of 230.4 m and a height of 146.6 m. Geometric volume = (1/3) × 440² × 280 = 18,069,333 cubic cubits = (1/3) × 230.4² × 146.6 = 2,594,000 m³. From this, two documented reductions are subtracted. First, the bedrock hillock: a natural limestone outcrop at the pyramid's core that the builders incorporated rather than quarried. Lehner (1997) estimates this at approximately 200,000 m³; alternative estimates in the literature reach up to 600,000 m³. The more conservative 200,000 m³ figure is adopted here, conservative in that a smaller hillock leaves more stone to be quarried and placed. That choice carries more weight than any other deduction in this calculation: the 400,000 m³ spread between the two estimates is some 293,500 blocks at the average block size derived below, or about 824 working days at the sustained placement rate of Layer 3 — roughly 134 times the volume of every internal void in the pyramid combined. The figures that follow should be read against that range rather than as a single determination. Second, internal voids: the King's Chamber (315 m³), five relieving chambers (410 m³), Grand Gallery (approximately 490 m³ depending on cross-section treatment), Queen's Chamber (188 m³), Subterranean Chamber and passages (750 m³), the ScanPyramids Big Void (estimated 400 m³; Morishima et al. 2017), the North Face Corridor (36 m³; Procureur et al. 2023), and additional minor shafts and likely undetected spaces (approximately 400 m³ additional). Total confirmed and estimated voids: approximately 3,000 m³ (the itemised figures above sum to 2,989 m³) — less than 0.2% of total volume, but documented and accounted for. The levels of the chambers Petrie surveyed are what assign them to a zone in Table 6: the Queen’s Chamber floor at about 40 cubits above the pavement, the gallery

doorway at about 41 and the upper end of the gallery floor at 82, the King's Chamber floor at 82, and the top of the construction chambers at about 122, a level he marks as uncertain (21.2, 21.7, 42.9, 43.0 and 64.1 m); the well in the subterranean part lies about 61 cubits below the base (Petrie 1883). The two spaces found by the ScanPyramids survey are placed by their own reports: the Big Void lies above the Grand Gallery and so above 82 cubits (Morishima et al. 2017), and the corridor behind the North Face chevrons was reconstructed in a density slice between about 37 and 45 cubits above the ground, 19.5 and 23.5 m (Procureur et al. 2023). Net stone volume in the final pyramid: 2,594,000 − 200,000 − 3,000 = 2,391,000 m³, which is the zone-by-zone total in Table 6.

A uniform average block size cannot meaningfully describe a structure whose lower courses contain blocks of 2.2–3.75 m³ (6.5–10 tonnes, documented by Petrie: first course 148 cm high) and whose upper courses contain blocks of 0.3–0.6 m³ (barely 1.3 tonnes, upper courses approximately 50 cm high). Each zone presents a fundamentally different construction problem. No single construction method is likely to have governed all zones equally. Table 6 presents the final pyramid stone count only. Under the Choi overbuild model discussed in Layer 3 below, the initial trapezoidal mass of approximately 8 million tonnes corresponds to approximately 2.35 million block-equivalents prior to the carve-down phase, taking the same 3.4-tonne average block as the finished structure (Choi publishes tonnages rather than a block count, so the count is derived from his mass); the 1,754,500 blocks shown here represent the net stone after the outer faces were cut to the final 51.84° slope.

Table 6: Stratified Block Volumes by Zone — Great Pyramid

Zone	Height	Volume (m^3)	Avg block size	Est. blocks	Primary bottleneck
Lower courses	0–30 m	1,065,600	2.2–3.0 m^3	~455,000	Heavy lifting (6–10 tonnes/block)
Middle courses	30–80 m	1,029,600	1.2 m^3	~858,000	Quarry and transport throughput
Upper courses	80–130 m	227,800	0.6 m^3	~380,000	Vertical raising — height adds time regardless of block size
Apex	130–146.6 m	3,000	0.3 m^3	~10,000	Negligible volume; extreme height
Tura casing	All heights	~60,000	1.0–1.5 m^3	~48,000	Precision fitting + cross-river Tura delivery (Merer diary)
Granite elements	Various	~5,000	Varies	~3,500	Copper-saw rate ~12 cm^3/hr per 2-person team (Stocks 2001) + 60-day Aswan round trips — absolute timeline floor
TOTAL		**2,391,000**		**~1,754,500**	**Total mass consistent with ~6**

Zone	Height	Volume (m^3)	Avg block size	Est. blocks	Primary bottleneck
		m^3		million tonnes	

For the entire Giza complex, including Khafre's pyramid (~2,211,000 m³, ~5.5 million tons), Menkaure's pyramid (~235,000 m³, ~0.59 million tons), the subsidiary pyramids (~285,000 m³, ~0.71 million tons), the itemised monuments give a standing stone volume of approximately 5.1 million m³, to which the associated temples and causeways add a further amount not itemised here. All tonnages in this section apply a limestone bulk density of 2.5 t/m³, the value used for the same class of calculation by Tallet (2017) and the figure underlying Table 6, giving approximately 12.8 million tons; the published range for Egyptian building limestone runs from about 2.2 t/m³ (Nuzzolo 2015) to 2.6 t/m³, which places the total between roughly 11.3 and 13.3 million tons. This figure includes only finished monuments; quarry waste, removed bedrock, and construction debris would add additional mass, bringing the total material handled to approximately 13–14 million tons.

Documented Technologies

Key documented constraints that any viable construction model must accommodate include:

- **The Ahramat Branch waterway** (Ghoneim et al. 2024): a 64-kilometre extinct Nile channel confirmed by satellite radar and deep soil cores, running along the foot of the Western Desert plateau beside the entire pyramid chain, active at high-water levels during Dynasty 4. The causeways of the Giza pyramids terminate at its former banks. The valley temples were its harbours. The pyramid may have risen not from a desert but from the edge of a major river channel.

- **The Hatnub rope-and-post haulage system**, excavated in 2018 by the University of Liverpool and the French Institute for Oriental Archaeology, dated to Khufu's reign by two inscriptions on site (Gourdon 2017). The system — a central ramp flanked by staircases with postholes into which wooden posts were set, with ropes running from loaded sleds to those posts — is interpreted by the excavators as a force multiplier, enabling blocks to be hauled up slopes of 20 percent or more. The ramp is excavated and its Khufu dating rests on two rock-cut inscriptions recorded at the site. Its interpretation as a haulage force multiplier was announced by press release in November 2018 and has not been published as a peer-reviewed excavation report; Brichieri-Colombi (2019) has published a peer-reviewed critique arguing that the system does not scale to pyramid construction. The excavation is documented; the mechanism is an interpretation, and a contested one.

- **Binary hekat mathematics**: Ancient Egyptian scribes used a binary fraction series — 1/2, 1/4, 1/8, 1/16, 1/32, 1/64 — as their primary system for proportional division, documented extensively in the Rhind Mathematical Papyrus and the Egyptian Mathematical Leather Roll in the context of grain and volume measurement (Gillings 1972). This series is mathematically identical to a binary mechanical advantage progression. The extension of the hekat series to mechanical advantage calculation is the present author's inference; Gillings (1972) documents the series for grain and volume measurement only. The mathematical equivalence is established; its application to construction remains an inference.

- **Foundation precision**: The base is level to within 2.1 centimetres across its thirteen-acre base. The four faces are oriented to true cardinal north within a few arcminutes: Spence (2000) puts the deviation within 3/60 of a degree, and the 2015 Glen Dash Foundation survey reports the casing sides at −2′30″, −5′10″, −3′35″ and −4′21″, a mean of −3′54″ ± 44″ (Dash 2015). Dorner's survey (1981) gives the mean deviation of the north–south axis as −3′06″, with the east side at −3′24″ and the west at −2′48″ — errors at the limit of what is technically achievable by naked-eye observation. A line of holes cut along the pyramid three metres out from the base appears to have held the posts and ropes used to set out the baselines once the cardinal directions had been fixed (Lehner 1983; Haase 2004), which locates the surveying operation in the physical record rather than only in inference, using the same circumpolar astronomical knowledge this paper has traced across the entire tradition.

Layer 2: Derived Requirements (Model-Independent)

From the constraints above, several non-negotiable requirements follow. Any viable construction model must satisfy all of them simultaneously. Any future model that fails to satisfy these constraints simultaneously can be excluded within this framework.

Non-Compressible Bottleneck: Granite

Precision work on granite cannot be parallelised beyond the number of saw teams available. This constraint is independent of transport, workforce size, or ramp design; it is purely a function of material removal rate. Stocks (2001) measured a copper slabbing saw cutting Aswan rose granite with dry quartz sand abrasive at approximately 12 cm³ per hour per two-person team — a slot 3 cm deep and 95 cm long in 14 hours of cutting. The total kerf volume across all granite sawing operations (King's Chamber ceiling beams, walls and floor; five relieving chambers; antechamber portcullises; ascending passage plug blocks; plus Aswan face-dressing) is approximately 3.5–5.3 m³ of material removed by the saw. At Stocks's measured rate, one two-person team cutting 10 hours per day across a 300-day working year produces approximately 36,000 cm³ (0.036 m³) of kerf annually. To remove the full 3.5–5.3 m³ of granite kerf over a ten-year granite phase therefore requires approximately 10–15 simultaneous two-person saw teams — roughly 20–30 specialist workers sustained across that decade. This is consistent with the specialist-trade scale documented at Heit el-Ghurab and cannot be shortened by increasing the limestone gangs. This constitutes a non-compressible timeline floor: regardless of workforce size, the granite cannot be cut faster.

Blade consumption is a secondary but non-trivial logistical constraint. Stocks observed 7.5 mm of blade wear per 14-hour cutting day — approximately 0.54 mm per hour. With a starting blade 150 mm deep and a practical retirement point at roughly 50 mm of remaining height, each blade yields about 185 cutting hours, or 19 working days at 10 hours per day. At that rate, a single two-person team consumes approximately 16 blades per year. Across a ten-year granite phase at the 10–15 team level, total blade consumption comes to roughly 1,600–2,400 copper blades. At the documented blade mass of 14.5 kg of copper per saw, this represents approximately 23–35 tonnes of copper over the decade — 2.3–3.5 tonnes per year. That demand sits within the documented scale of 4th Dynasty metal logistics: the Sinai turquoise and copper mining expeditions, the Wadi al-Jarf harbour operations recorded in the same Merer papyri, and the Red Sea Desert copper sources together supplied the state with metal at the tonnage required.

Transport and Supply

The stone came from three sources. The majority of core limestone was quarried on the Giza plateau itself. White casing limestone came from Tura, approximately fifteen kilometres away, transported by boat as Merer's diary confirms. Granite for the King's Chamber — some ceiling beams reaching eighty tonnes — was shipped from Aswan, approximately 800 kilometres upstream, on specialized heavy-cargo barges (Klemm & Klemm 2010). On land, blocks were likely mounted on wooden sledges dragged by teams across prepared ground. The Mirgissa slipway — a purpose-built portage road with mud-brick reinforcement and preserved sledge tracks approximately 80 cm apart — provides archaeological confirmation that Egyptians regularly moved heavy loads over prepared surfaces using sledges (Creasman and Doyle 2010). Experimental studies have confirmed that wetting the sand ahead of a loaded sledge reduces the required pulling force by approximately half, consistent with a scene from the tomb of Djehutihotep showing 172 men hauling a fifty-eight-tonne statue with a figure pouring liquid at the front.

Timeline

The Merer papyrus provides an independent chronological anchor that is incompatible with a short Khufu reign. In a short 23-year single-reign model, the casing would need to have been placed and completed years before Year 26 — incompatible with Merer's documentation of active casing deliveries in Khufu's 26th or 27th regnal year. The evidence therefore supports a Khufu reign well beyond the Turin Canon's 23 years — securely attested to at least regnal year 26 or 27, which the excavators give as the latest known regnal year of Khufu, possibly longer on the evidence set out under Layer 2, and modelled here at approximately 40 years after Schneider (2002) — and a temporally overlapping construction sequence spanning the late reign of Sneferu and the reign of Khufu.

Sneferu reigned approximately 33 years (c. 2613–2580 BCE) on the chronology adopted here. That figure is contested: a recent revision of the dated worker's marks gives minimum reigns ranging from 28 to 35 years depending on the year-reckoning model applied, and removes the 24th-census attestation on which the older estimates of 47–48 years depended (Ciavatti 2022; see below). The value used here sits at the low end of that range. Khufu, his son and successor, is securely attested to at least regnal year 26 or 27. The excavators of Wadi al-Jarf state that date directly: one of the papyri mentions "the latest known regnal year (Year 26 or 27) of Khufu" (Tallet & Marouard 2016; Tallet 2017). That is a regnal year rather than a count, so it does not turn on whether the cattle count was annual or biennial at this period. The papyri are themselves dated to the year after the 13th cattle count, as is a rock inscription at Dakhla which Kuper and Förster (2003: 26) read as regnal year 27. A graffito on the cover stones of Khufu's second boat pit, dated to the 14th occasion, first month of Shemu, day 19, is published by Takahashi and Nishisaka (2016: 9). The authors do not assign it to a king; the pit's cover stones carry the names of both Khufu and Djedefre (2016: 12, n. 16), and the attribution of dated marks from Khufu's boat pits to one king or the other has long been disputed (Verner 2001: 375); AERA reads the date as Khufu's last count, regnal year 28–29 on the same biennial reading (AERA n.d.). That reading is treated here as supporting evidence only. Schneider (2002: 100–102) gives the reign as c. 2620–2580 BCE, a reign of 40 years, and reads the Turin Canon's 23 as cattle counts, which would allow up to 46 years. A 17th count is also on record: Petrie (1924: 60) reported the date of the 17th year, written in red paint on masonry above the King's Chamber, which on a biennial reading would give 34 years. He published neither its location nor a copy, and none of the surveys Verner (2001: 373–374) reviews has identified it, so it is offered only as a hypothesis in support of a long reign, not as a datum on which the model depends.

Phase Zero adopts a reign of approximately 40 years (c. 2580–2540 BCE), following Schneider (2002: 100–102): longer than the 26–27 years on which the direct evidence is secure, and within the 46 years his reading of the Turin Canon allows. The relationship between cattle-count regnal years and calendar years remains debated (Verner 2001: 415–416). The timeline below should be read as conditional on a long reign; a short reign would require compressing the phases into an implausibly brief window.

Hetepheres I — wife of Sneferu and mother of Khufu — was buried at Giza, not at Dahshur or Meidum where Sneferu built, with funerary equipment bearing Sneferu's name alongside seal impressions of Khufu (Dodson 2012). This suggests that Sneferu had a presence at Giza before Khufu ruled alone. Ankhhaf, a son of Sneferu and half-brother of Khufu, served as Khufu's vizier and chief overseer of works, with Merer's diary placing him in direct command of construction logistics in the pyramid's final years (Tallet & Marouard 2014). The architects, quarry teams, and boat crews who built Sneferu's Red Pyramid may have continued under Khufu on a project whose architectural grammar — corbelled ceilings, tripartite interior, the 43° slope angle — appears to flow directly from what Sneferu's three pyramids had tested.

Layer 3: Candidate Model Testing

At present, no construction model for the Great Pyramid has achieved consensus within the engineering or archaeological literature. External ramp systems, internal ramp hypotheses, and counterweight proposals each resolve some constraints while failing others. For example, large external ramp models struggle to satisfy material volume and slope constraints, while internal ramp models face unresolved issues in upper-course access. The role of the present analysis is therefore not to select a definitive method, but to test whether a given model can satisfy the full set of independently documented constraints without contradiction. Any model that fails to meet these constraints can be excluded; models that satisfy them remain viable but unproven. One physical feature bears on every candidate alike. The muon radiography of 2017 identified a void above the Grand Gallery with a cross section comparable to it and a length of at least 30 m, and its discoverers state that there is at present no information about its role (Morishima et al. 2017). A space of that size inside the structure is a constraint any construction model has to accommodate, whether as a deliberate chamber, a by-product of the raising method, or a structural measure, and the framework below does not attempt to decide which.

The Shemsu Hor archives (as preserved in institutional memory) may have supplied the cosmological specification: what to build, how to orient it, and what it meant. The engineering capacity to execute that vision at Giza scale appears to have developed iteratively across the late 3rd and early 4th Dynasties. Several mechanical models have been proposed. One — the Trapezoidal Step Pyramid Hypothesis (also called “cannibal construction” or “build-by-unbuilding”) proposed by independent researcher Huni Choi (unpublished; see Non-Peer-Reviewed Sources) and analyzed in Lee (2026) — is examined here as a test case.

The Model

Choi’s model suggests that the pyramid was first overbuilt as a much larger trapezoidal or stepped mass with integrated gentler ramp slopes (approximately 7°) and a broad, flat working platform at the top. Once the full height and internal structure were in place, the outer faces were carved down from the top outward to the final design slope of seked 5½ palms (51.843°), with excess material systematically recycled on-site. Choi estimates the initial overbuild mass at approximately 8 million tons, the final Great Pyramid at roughly 6 million tons, and the approximately 2 million tons of stone removed during carving as recycled into Khafre’s pyramid and other annex buildings.

An independent visual analysis of Khafre's remaining casing stones by History for Granite (2024) has also identified patterns of tapered bonding (keying) stones consistent with simultaneous sectional construction. The quantitative outputs of Choi's model are treated here strictly as internal consequences of the model for testing purposes, not as independently verified measurements. No peer-reviewed paper has confirmed these figures; they are presented as the model's projections, not as established fact.

Testing Against Constraints

Timeline. The placement-rate question is the most scrutinised element of any pyramid construction model. Three approaches are shown below. They are not fully independent: Approach 2 shares its block-count inputs with Approach 1 and requires an assumed utilisation factor, and Approach 3 applies an assumed mechanical advantage rather than a measured one. They are offered as an internal consistency check on the model's own arithmetic, not as mutual corroboration.

Fixed inputs — what we know before any calculation:

• Overbuild block-equivalents (Choi model, 8 Mt at the 3.4 t average block): ~2.35 million blocks
• Overbuild phase: 22 working years — Khufu Y1–18 plus the four-year Sneferu overlap
• Working days per year: 300 (standard Egyptological assumption; Merer diary confirms seasonal cadence)
• Total working days available: 22 × 300 = 6,600 days
Total project workforce, all roles: ~10,000 (Hawass & Lehner 1997; Lehner 2015). This is an estimate, not a documented count, and it is a middle value: published totals for Khufu range from Lehner's low figure of around 2,000 to the 36,000 of Borchardt and Croon accepted by Verner (Lehner 2015: 471). It counts everyone — quarrymen, hauliers, dressers, and the bakers, brewers, potters and toolmakers who supplied them — not the crews at the placement face, which Approach 2 below derives separately as ~61 per cent of this total. It is consistent with the provisioning evidence, where the faunal remains at Heit el-Ghurab imply meat for on the order of ten thousand people per day (Lehner 2015: 407–8)
• Average overbuild block mass: 1.36 m³ (the final pyramid's average, 2,391,000 m³ ÷ 1,754,500 blocks, carried over to the overbuild) × 2.5 t/m³ = ~3.4 tonnes

Approach 1 — Top-Down: Total blocks ÷ Total time

The simplest possible check. No model required — just divide what needs to be placed by how long you have.

• Total overbuild blocks: ~2,350,000
• Total working days: 6,600
• 2,350,000 ÷ 6,600 = **~356 blocks per day (sustained average across full overbuild phase)**

Approach 2 — Bottom-Up: What can 10,000 workers physically do?

Start from the workforce and calculate how many blocks they can place simultaneously at peak.

• Average overbuild block on a lubricated sled at the model's ramp angle (~7°):
• Friction force: 3,400 kg × 0.12 (wet-surface coefficient) = 408 kg

• Slope component: 3,400 × sin(7°) = ~414 kg
• Total resistance: 408 + 414 = 822 kg; at 50 kg effort/man = ~17 men per team
• Maximum simultaneous teams: 10,000 ÷ 17 = ~588 teams
• At 1 block placed per team per working day: **~588 blocks/day with every team active**

Why is this higher than Approach 1's 356 blocks/day? Not all 10,000 workers are placing blocks at the same moment. The workforce divides its time:

• ~39% at any given time: quarrying, transport, stone dressing, logistics
• ~61% at any given time: active block placement at the face
• 588 × 0.61 = **~359 blocks/day sustained average, within one per cent of Approach 1. The 61% utilisation factor is an assumption selected to reconcile the two figures, not a value derived independently of them, so the agreement between them is built in rather than found.**

During peak phases — when logistics chains are fully loaded and all placement teams are simultaneously active — the rate approaches 588 blocks/day. Scheuring (2025) frames the pace of roughly one block per minute as the rate a twenty-year programme would demand — a problem his pulley-and-counterweight model sets out to solve — rather than as a demonstrated ceiling, so it is cited here as a statement of the scale of the requirement, not as corroboration of the figure above.

Approach 3 — Wedjat Cross-Check: Does the binary fraction system validate team sizes?

The average overbuild block (~3.4 tonnes) uses sled physics to derive ~17 men per team (Approach 2). The Wedjat rope-and-post system is not required for these routine elements. Where the Wedjat becomes essential is for blocks too heavy for simple sled dragging. Applying the binary mechanical advantage at different fractions:

Element	Mass	Method / MA	Team size
Average overbuild block	~3.4 t	Sled + slope physics (no MA required)	**~17 men**
Heaviest lower-course limestone	~10 t	Wedjat 1/8: 10,000 ÷ 8 = 1,250 kg ideal; ×1.15 friction = 1,437 kg; ÷ 50 kg/man	**~29 men ≈ 30 men**
King's Chamber granite ceiling beams	~80 t	Wedjat 1/64: 80,000 ÷ 64 = 1,250 kg ideal; ×1.15 friction = 1,437 kg; ÷ 50 kg/man	**~29 men ≈ 30 men**

The key observation: by selecting a larger Wedjat fraction (more rope-and-post stations), the same ~30-man crew handles both the heaviest lower-course limestone and the 80-tonne granite beams. The Wedjat system created standardised crew sizes across the full range of construction challenges. A foreman did not calculate per block — he selected the appropriate

fraction, set up the corresponding number of posts, and deployed his standard crew. The two Wedjat calculations produce identical results because 80,000 ÷ 64 = 1,250 kg (granite beams) and 10,000 ÷ 8 = 1,250 kg (lower limestone) — the binary fractions scale the advantage proportionally to block weight, producing the same ideal load in both cases. This is not coincidence; it is the binary series working exactly as designed.

The 17-man sled teams (routine overbuild) and the 30-man Wedjat teams (heavy lifts) are therefore not two separate assumptions — they are two points on the same mathematical curve. The same binary mathematics documented in the Rhind Mathematical Papyrus for grain measurement was, in this inference, the workforce management system for the most complex construction project of the ancient world.

Summary — three approaches, one answer:

• Approach 1 (top-down: blocks ÷ days): ~356 blocks/day sustained average
• Approach 2 (bottom-up: workforce capacity × assumed 61% utilisation): ~359 blocks/day sustained average
• Approach 3 (Wedjat cross-check): derives a ~30-man crew for the heavy lifts. This is a separate calculation from Approach 2, which produced only the ~17-man sled team; it does not validate Approach 2, and both rest on the same assumed 50 kg of effort per man.

588 = the placement teams the workforce can field at once, at one placement per team per day.
~356 = realistic sustained average across the 22-year overbuild phase

Neither figure requires any capability beyond what 4th Dynasty evidence documents.

Material flow. If the model is treated as a working hypothesis, it implies a non-additive block flow in which material removed during the carve-down phase could be reused in adjacent construction projects. After the carve-down, the final pyramid contains the 1,754,500 stratified blocks calculated independently above, and the carved-off material — roughly 1.3 million recycled-block equivalents at 1.5 tonnes each — would be available for Khafre's construction. That recycled mass would represent roughly 37 percent of Khafre's total ~5.5-million-tonne mass; the remainder would have been quarried fresh at the Khafre site, consistent with the presence of Khafre-era quarries on the plateau.

Bonding stones. An independent analysis of Khafre's casing stones (History for Granite 2024; see Non-Peer-Reviewed Sources) has identified a pattern of tapered bonding stones (keying stones) — stones cut with slanted ends that are lifted slightly above a matching slanted stone, then lowered to complete and lock a row of masonry. The analysis, as cited in Lee (2026), suggests that different sections were laid simultaneously by different crews and then stitched together using these keying stones; that there are no bonding stones at the centers or corners, indicating these were starting lines rather than ending lines; and that all three faces show the same pattern. This observation is provisional: it derives from a non-peer-reviewed source and has not been confirmed by independent architectural survey. It is noted here as a potential constraint that, if verified, would be consistent with the absence of a large external ramp, but it currently carries no independent evidentiary weight.

Mechanical advantage. Applied to the 80-tonne granite beams of the King's Chamber — the specific elements Scheuring (2025) identifies as a central unresolved problem — the arithmetic of the binary hekat series is straightforward. A 64:1 mechanical advantage (the maximum in the binary series) would reduce an 80-tonne load to 1.25 tonnes ideally; accounting for rope friction at approximately 15 percent gives 1.44 tonnes of required effort, manageable by approximately

30 men pulling at 50 kg each. This figure is cross-validated in the Timeline section above, where the same ~30-man team size emerges from applying the Wedjat 1/64 fraction to the granite beams and the 1/8 fraction to the heaviest lower-course limestone blocks — confirming that standardised crew sizes, not block-by-block recalculation, governed the project. Scheuring (2025) identifies physical evidence consistent with this model, including rope-guidance grooves in the Antechamber and friction-smoothened floors in the Ascending and Descending Passages, suggesting the pyramid's internal architecture functioned as an integrated mechanical system. The Grand Gallery provides the physical geometry: eighty-eight cubits of floor length (46.1 m), 26.5° slope, polished floor, twenty-seven symmetrical pairs of slots and niches — fifty-four in all — of unknown purpose, and an Antechamber with semi-circular granite notches suited for log-based pulley mounting, all features Scheuring analyses in detail (Scheuring 2025). That these features remain unexplained is not a fringe position but the state of the question in the peer-reviewed literature. Miatello (2010), examining the gallery in detail, observes that the conventional explanation relates them to the parking of the granite plugs, but that only three or four granite blocks were presumably used to plug the ascending corridor while a much larger number of slots and niches are found in the gallery, and concludes that previous interpretations of the niches, slots, cuttings and grooves are unsatisfactory. The orthodox account therefore leaves a numerical mismatch of roughly an order of magnitude unaccounted for, which is what licenses considering alternative functions at all. A counterweight system, with a loaded sled sliding down the Gallery under gravity and ropes looped over the Antechamber logs, would transmit force upward. This simplified calculation addresses force requirements only; real systems would incur additional losses from rope friction, anchoring stress, and control constraints, which would increase the required effort. This is not proven. It is a hypothesis consistent with all documented 4th Dynasty technology: rope (documented), wooden posts (Hatnub), polished surfaces (Hatnub, Grand Gallery floor), counterweights (gravity and stone), and binary force ratios (hekat series — the mathematical equivalence is established; its application to construction remains an inference). No tool beyond what the 4th Dynasty demonstrably possessed would be required.

Feasibility Synthesis

The following synthesis represents the internal implications of this specific model under the constraint framework; alternative models may produce different distributions while satisfying the same constraints.

Table 7: Feasibility Synthesis — Construction Timeline

Phase	Reign(s)	Duration	Activity
Sneferu's three pyramids (Meidum, Bent, Red)	Sneferu	33 years	Iterative learning; Meidum casing failure (date disputed — Lauer 1976 argues against a collapse during construction) → Bent Pyramid angle correction → Red Pyramid success; copper-saw precision refined across three builds
Sneferu initiates Giza overbuild (hypothetical)	Late Sneferu	~4 years (Sneferu Y30–33)	Trapezoidal stepped mass quarrying and placement begins at Giza; Sneferu's final years may have overlapped with Khufu's

Phase	Reign(s)	Duration	Activity
			preparation
Khufu inherits, continues overbuild	Early Khufu	~18 years (Khufu Y1–18)	Overbuild completion; granite elements placed (King's Chamber, relieving chambers); subterranean chamber cut
Carve-down and recycling phase	Middle Khufu	~8 years (Khufu Y19–26)	Top-down carving from flat working deck; outer faces cut inward to 51.84°; recycled stone moved to Khafre's pyramid site
Final casing, polishing, temples, causeways	Late Khufu → early Khafre	~14 years (Khufu Y27–40)	Tura casing delivered — Merer diary Khufu Y26–27 captures transition from outer-face carving to casing placement; precision polishing; mortuary temple, valley temple, causeways
Giza project total (hypothetical)	**Sneferu late years + Khufu**	**~44 years**	
Full program total (hypothetical)	**Sneferu R&D + Giza**	**~69 years**	

Two timelines are consistent with the constraint framework developed above. The Giza-only project — from Sneferu's possible initiation of overbuild quarrying in his final years to the completion of Khufu's temples and causeways — may have required approximately **44 years**. When Sneferu's three experimental pyramids (Meidum, Bent, Red) are included as a necessary R&D phase, the full program might have spanned approximately **69 years** (Sneferu's 33-year R&D reign plus Khufu's modelled 40-year reign, minus the 4-year Sneferu–Khufu Giza overlap). These figures are not claims of precision; they are transparent attempts to reconcile the archaeological data with a realistic pace of skilled labor (peak approximately 10,000 workers, 300-day work year) while matching Merer's Year 26–27 casing activity to the logistical inflection point between completion of outer-face carving and onset of Tura casing delivery. Table 7 tabulates Sneferu's reign and the Giza project only; the minor step pyramid programme of c. 2613–2590 BCE ran concurrently with Sneferu's reign and is additional to these totals, which is why the accumulated construction time given at the opening of this section is the larger figure.

The independent bottlenecks identified above — block placement rate, copper saw throughput, blade and copper consumption, Tura casing delivery cadence, and granite haulage — are all consistent with the same calculation. Sneferu's iterative sequence — Meidum, Bent Pyramid, Red Pyramid — represents a programme of accumulated mastery in these techniques spanning most of Sneferu's reign. That the sequence was iterative — that the builders altered the design in response to what the work itself revealed — is not universally accepted. Nuzzolo (2015) argues the opposite: that the Bent Pyramid's double slope was intended from the outset, and that it and the Red Pyramid were planned together as a single dual complex, citing their identical 105 m height, the shared name Kha-Snefru, and the double-pyramid determinative in

the decree of Pepi I. Against this, Monnier and Puchkov (2016), reassessing the monument's construction phases and structural pathology, conclude that the builders did change their project several times, and propose a revised history of the building on that basis. The iterative reading adopted here follows the most recent technical reassessment, but the question is open, and the capacity argument does not depend on its resolution: whether the changes at Dahshur were corrections or intentions, the same three monuments were built, and the accumulated experience is the same. The model adopts a 33-year reign, at the low end of the values defensible on current evidence; Sneferu's regnal length remains contested, and a recent revision of the dated worker's marks from Meidum and Dahshur gives minimum reigns of 28 years under an octaétéride model, 29 under a Metonic lunisolar model, and 35 under the standard biennial reading, the older figure of 47–48 years depending on a 24th-census attestation now shown to be unreliable (Ciavatti 2022). The shorter value is retained deliberately: a longer reign relaxes the constraint rather than tightening it, so the timeline presented here is the least favourable case for the argument rather than the most. The Phase Zero minor step pyramids, built at the Shemsu Hor's own sites across the same period, may represent the same tradition expressing itself in parallel at provincial scale. By the time Khufu's workers drove the first shaft into the Giza bedrock, there were three decades of pyramid-building experience behind them and a Phase Zero programme of distributed territorial markers encoding the astronomical and institutional tradition at every major site in Upper Egypt. The precision at Giza was earned, not invented.

What Remains Unknown

None of the above constitutes proof. The constraint analysis, the timeline calculations, and the copper-saw requirements are grounded in documented evidence and independent of any construction model. But the Choi model, the bonding stone observations, and the counterweight proposal are all hypothetical. They are consistent with the constraints — but consistency is not demonstration. Multiple construction methods could satisfy the same requirements.

What this paper cannot answer is more substantial than what it can. The supply chain, workforce organization, and waterway access are well documented. The precise mechanics of the upper courses and heaviest granite lifts — particularly the 80-tonne beams — remain open questions. Whether elements of Choi's overbuild-and-carve approach, counterweight systems in the Grand Gallery (Scheuring 2025), aspects of internal ramp ideas, or some combination thereof were used cannot be determined from current evidence.

What is clear is that the 4th Dynasty Egyptians possessed the organizational capacity, tools, and generational experience that would have been required to execute a project of this scale. The constraint framework developed here — the granite bottleneck, the Merer chronology, the stratified block analysis, the Hatnub force-multiplier — is independent of model selection and remains applicable as a falsification framework for future hypotheses.

The tradition documented in this series — from Nabta Playa through HK6 and Phase Zero — may have supplied the cosmological grammar that told them what to build and why. The state capacity that allowed them to do so at Giza scale appears to have developed over decades of iterative practice. The casing joints Petrie measured on the north side average 0.5 millimetres (Petrie 1883). Eighty-tonne granite beams were carried 800 kilometres and positioned to sub-centimetre tolerances in a chamber whose floor Petrie places some forty-three metres above the base. How they built it at that precision and at that pace remains, honestly, one of the outstanding questions of the ancient world.

14. Limitations and Alternative Interpretations

The argument presented in this paper is inferential at its upper tiers, and several limitations must be acknowledged directly.

No direct textual evidence links the MSPs to the Shemsu Hor. No inscription at any of the seven pyramids names the Followers of Horus or describes the purpose of these structures. The connection rests on spatial correlation: the MSPs sit at Predynastic ceremonial centers that later Egyptian tradition associates with the Shemsu Hor. This is a geographic argument, not a textual one. However, the absence of direct textual evidence cuts both ways. The Wedjat — the Eye of Horus — is a symbol that this series reads, as an interpretive comparison rather than evidence, against the concentric topography of the Richat (Paper I; Levy 2026a); its drop and spiral have a documented Saharan precedent in the tear-and-spiral eyes of engraved Messak cattle (van Albada and van Albada 2000: 69), and the Zep Tepi tradition describes a circular, watery origin in the west that aligns with the hydrological history of that landscape. If these traditions encode geographic memory rather than pure mythology, the absence of direct textual links to the MSPs reflects the preliterate context of the tradition's origin, not its nonexistence. Prediction 6 (spatial discrimination of MSP site selection) provides a test of the geographic argument that does not depend on textual confirmation.

Convergent evolution remains a live alternative. Independent cultures can and do develop similar symbols, rituals, and astronomical orientations without contact. The MSP builders could have oriented el-Kula toward Meskhetyu without inheriting any knowledge from Nabta Playa pastoralists. The paper grants this possibility throughout. What the consilience argument establishes is that the repeated conjunction of the same symbolic package — cattle cult, concentric geometry, adze-like forms, circumpolar emphasis — across chronologically successive sites among genetically related populations is more parsimoniously explained by transmission than by repeated independent re-invention. This is a philosophical argument about parsimony, not a demonstration of contact.

It may be noted that the mechanism of archaeological rediscovery as a driver of cultural transmission — which this paper proposes for the Meskhetyu tradition — has been independently documented elsewhere in the Egyptian record. Miniaci (2024) has argued that Late Middle Kingdom votive figurines reflect the rediscovery of Early Dynastic deposits during temple renovations, with a temporal gap comparable to that between the HK6 elite cemetery and the MSP program. While this parallel does not demonstrate that the same process occurred at Hierakonpolis, it indicates that the category of explanation proposed here is methodologically recognized in Egyptian archaeology and is not inherently implausible.

The transmission mechanism proposed at Level 3 — local astronomical knowledge gradually absorbed and formalized by the state — has an independently documented parallel. Alcouffe et al. (2025) demonstrate the same dynamic at Adaïma, near Hierakonpolis, where rural funerary practices involving celestial orientations, bodily dismemberment, and ritual pottery breakage were progressively co-opted by elites and later codified in the Pyramid Texts. The authors characterize this as a process by which "the nascent state co-opts local traditions... to consolidate central authority," and they explicitly document bidirectional transmission between non-elite communities and elites, noting that horizontal cultural transmission "reflects interactions between non-elite social groups and elites."

The mechanism required by the corridor transmission model — pastoralist astronomical knowledge entering Nile Valley elite practice — is therefore not unique to this paper's

hypothesis; it is a documented pattern in the regional archaeological record. The authors themselves make a similarly cautious inferential argument for connections between Adaïma's ritual practices and the Pyramid Texts, noting that "although such a link remains hypothetical, it raises the prospect" of earlier local traditions shaping later royal ideology. The present paper's argument for Meskhetyu transmission remains testable via the predictions in Section 12, but the type of process proposed is archaeologically plausible and independently attested in the same region during the same period (Alcouffe et al. 2025).

Table 8: Competing Level 3 Frameworks — Handling of Key Limitations

Limitation	Model A: Corridor Transmission	Model B: Regional/Internal + Western Desert	Model C: Purely Internal / Convergence
No direct textual evidence for MSP–Shemsu Hor link	~ Geographic memory	~ Later ideological construct	~ Ahistorical myth
Convergent evolution	Parsimony favors transmission	Shorter diffusion helps, doesn't resolve	Primary mechanism
Takarkori lineage in Fezzan	✓ Source population	~ Stay-behind; no eastward move	~ Not predicted
el-Kula measurement unreplicated	~ Prediction 7 pending	~ Same	~ Same
Biological markers (isotopes, aDNA)	Positive → Model A	Negative → Model B	Negative → Model C
Zawiyet el-Mayitin & Seila weaker	~ 2 of 7; 5-site core stands	~ Same	~ Same
Overall parsimony	Higher	Moderate	Lower

Table 8. Three Level 3 models assessed against Section 14 limitations. ✓ = model predicts or is unaffected. ~ = model accommodates with stated assumption. All models accept the Level 1–2 base. Predictions in Section 12 discriminate between them.

The morphological diversity observed in Predynastic and Early Dynastic Egyptian populations is not accounted for by simple geographic clines at the scale so far measured. Zakrzewski (2007) tested for isolation by distance and found no significant relationship between biological distance and geographic distance among Egyptian cemetery samples, so that the differences between them are not patterned in space. The reach of that result should be stated as she states it: an isolation-by-distance model “may not be appropriate for these groups”, while isolation by distance operating over shorter distances than those separating her cemeteries would be undetectable in her data (Zakrzewski 2007: 506). Geographic clines are therefore shown to be insufficient at the scale measured rather than excluded. This finding is consistent with the

hypothesis that migration — whether from the Saharan corridor or elsewhere — contributed to the heterogeneity observed in the Nile Valley during the period of state formation.

The genomic evidence and the corridor hypothesis. Two independent genomic studies now provide data directly relevant to the Level 3 transmission hypothesis. Salem et al. (2025) documented a distinct, isolated North African lineage at Takarkori (Libya), closely related to 15,000-year-old foragers from Taforalt (Morocco), and explicitly concluded that "the Green Sahara was not a migration corridor between Northern and sub-Saharan Africa." Salem and colleagues frame the result as showing that pastoralism spread through cultural diffusion rather than through significant human gene flow, with local groups adopting livestock while largely remaining in place. This requires direct engagement: Salem et al. argue against bidirectional gene flow between sub-Saharan and North African populations — that is what the phrase "migration corridor between Northern and sub-Saharan Africa" refers to. The corridor hypothesis of Papers I–III is categorically different: it posits northeast-trending movement of an already North African population within North Africa toward the Nile Valley. The corridor is intra-North African, not trans-Saharan. Salem et al. document exactly what the hypothesis requires: a west-to-east geographic footprint that is the spatial precondition for the northeast dispersal the hypothesis proposes. The cultural diffusion finding removes a false alternative: had Salem et al. found massive sub-Saharan gene flow into Takarkori, this would have complicated the corridor argument. They found the opposite. The stronger form of their conclusion should also be met directly. Salem and colleagues argue not merely against sub-Saharan gene flow but for cultural diffusion in place: that herding was adopted by a resident, deeply divergent lineage rather than carried in by incomers. Three considerations bear on how far this reaches the present hypothesis. First, their genomes date to approximately 7,000 years ago, within the humid phase and well before its collapse; they describe the Central Sahara as it was while it remained habitable, and do not test what became of that population when the lakes failed. Second, an isolated and genetically distinctive lineage is precisely what a later dispersal would require in order to be detectable at all, so the isolation finding is a condition of the hypothesis rather than an obstacle to it. Third, the vector Salem and colleagues describe for the arrival of pastoralism runs east to west, entering along the Sinai and Red Sea routes and reaching the Central Sahara around 8,300 years ago; the movement proposed here is a later and separate west-to-east displacement of people under aridity, not a claim about how livestock first arrived. The two are compatible, but the distinction should be explicit rather than assumed.

Whole-genome sequencing of an Old Kingdom Egyptian from Nuwayrat (Middle Egypt), radiocarbon-dated to 2855–2570 cal. BCE, provides a second, independent data point directly contemporary with the MSP program. The individual (NUE001) carries approximately 77.6 ± 3.8% ancestry best represented by Middle Neolithic North African populations (Morocco, 4780–4230 BCE), with the remaining approximately 22.4 ± 3.8% related to Neolithic Mesopotamian populations, and no detectable sub-Saharan African ancestry (Morez Jacobs et al. 2025). Multi-isotope analysis of dental enamel confirms a local Nile Valley childhood, indicating the North African ancestry represents an established population component rather than first-generation migration — consistent with the integration of Saharan-derived populations centuries earlier, as documented at HK6.

The eastern Fertile Crescent component documents a separate ancestry stream arriving from a different geographical direction, probably via Mediterranean or Red Sea routes, and does not conflict with the western Saharan corridor model; it suggests rather that Old Kingdom Egypt was the product of multiple demographic inputs, of which the Saharan pastoralist contribution is one. Critically, the Nuwayrat genome shows no direct genetic continuity with Third Intermediate Period individuals (787–544 BCE), who carry significant Bronze Age Levantine ancestry absent

in the Old Kingdom sample. The Level 3 transmission hypothesis is therefore time-bounded to the Old Kingdom population specifically. The successful recovery of whole-genome data from an Old Kingdom context also demonstrates the technical feasibility of the aDNA analysis proposed in Prediction 1. Prediction 1 is designed to test whether the Takarkori lineage was physically present at Hierakonpolis specifically — as opposed to merely culturally influential at a distance — which remains the question that separates population movement from ideational transmission.

Two categories of evidence would move this question from interpretation to demonstration. The first is geochemical: if hard-stone vessels of the Naqada period match the tri-lithic suite documented at the Richat — iron-stained rhyolite, black gabbro, red-weathering carbonatite (Matton & Jébrak 2014: 113; Taylor & Giles 2015: 27) — using LA-ICP-MS trace element analysis, the material itself is non-local and convergence becomes an inadequate explanation (Levy 2026a, Section 12, Prediction 7 of that paper). The second is genetic: if A-Group Nubian skeletal remains carry the Takarkori North African Neolithic lineage documented by Salem et al. (2025), the "mythological ancestors" interpretation of the Shemsu Hor must contend with a physical population moving eastward along the corridor at the predicted time (Levy 2026c, Section 12, Prediction 8 of that paper). These tests are not requests for new excavations. The vessels and the bones exist in museum collections.

The astronomical argument hinges on a single measurement awaiting replication. Belmonte et al.'s (2005) measurement of el-Kula's secondary axis anchors the Meskhetyu orientation claim. Independent verification by a second archaeoastronomical team (Prediction 7) is a prerequisite for the astronomical transmission argument to stand — a point this paper states explicitly rather than treating as a vulnerability to be minimized.

The genetic and corridor evidence depends on Papers I–III. The genetic and corridor evidence depends on Papers I–III (Levy 2026a, 2026b, 2026c). This bridging paper does not re-argue the Saharan corridor, the genomic continuity, or the Shemsu Hor institutional-memory case. Those arguments stand or fall on their own evidence. A reviewer who rejects the corridor model should still engage with the MSPs as a Phase Zero of the pyramid tradition (Level 1) and with their spatial correlation with Predynastic ceremonial centers (Level 2).

Biological markers offer a discriminating test beyond symbolism. Non-local isotopic signatures — strontium and oxygen — in Predynastic elite burials would demonstrate that specific individuals spent their childhoods outside the Nile Valley in regions consistent with the western Saharan basement complex (Prediction 2, this paper). Recent methodological advances in strontium isoscape analysis provide a standardized framework for such provenance testing, with best-practice protocols now established for distinguishing local from non-local signatures in archaeological human remains (Spies et al. 2025). An organism of the *Brucella* group, a zoonosis associated with cattle herding, is authenticated with ancient damage at corridor sites in Paper II (Levy 2026b). That signal resolves to the genus and not to a species, so it establishes the organism rather than brucellosis, and no published, directly dated Egyptian skeletal record of brucellosis was located there for comparison. The isotopic test above is not an interpretation of symbols; it would be physical evidence of movement.

The genetic corridor itself is now documented at every node by independent research teams. Salem et al. (2025) confirmed the Taforalt lineage at Takarkori (Libya, c. 7,000 BP). Lipson et al. (2025) subsequently documented the same Maghrebi forager ancestry across nine individuals from Algeria and Tunisia spanning 15,000–6,000 BP, finding that the eastern Maghreb was "far less affected by external gene flow than the rest of the Neolithic Mediterranean" — confirming that the lineage remained intact as it extended eastward. Taken together, van de Loosdrecht et

al. (2018) at Taforalt (Morocco), Lipson et al. (2025) across the eastern Maghreb, and Salem et al. (2025) at Takarkori (Libya) now provide peer-reviewed genetic continuity at every node from Morocco → Algeria/Tunisia → Libya, with the Nuwayrat genome (Morez Jacobs et al. 2025) anchoring the Nile Valley endpoint. Each study establishes ancestry at its own location; none tests a west-to-east movement directly. Together they establish that a related North African lineage is attested at Morocco, the eastern Maghreb and the central Sahara across the relevant period — a necessary condition for the corridor proposed in Paper I rather than a demonstration of it.

It is worth noting that the research communities studying Saharan pastoralist monumentalism and Nile Valley state formation increasingly overlap. The most recent Nabta Playa monograph (Schild et al. 2025) was formally reviewed by Maria Carmela Gatto, co-author of the Atbai Enclosure Burials study (Cooper et al. 2026) and co-editor of the Garamantes burial volume (Gatto et al. 2019). This institutional proximity does not validate any specific hypothesis, but it reflects a growing recognition that the Saharan and Nilotic archaeological records are best understood as part of a connected landscape rather than as isolated traditions.

The Epigraphic Silence. The MSPs have no inscriptions. None of the seven pyramids bears a text naming its builder, stating its purpose, or identifying the deity or constellation to which it was oriented. Function is inferred entirely from material evidence: architecture (shared plan, identical dimensions, no burial chambers), spatial distribution (clustering at Predynastic ceremonial centres), archaeological context (food offering installations at Edfu, construction ramps at Sinki), and astronomical orientation (the quarter-cardinal Meskhetyu alignment at el-Kula). This is not a weakness unique to the MSPs — much of the archaeological record is preliterate or non-textual, and material evidence routinely supports functional inference in the absence of inscriptions. The spatial discrimination prediction (Prediction 6) is designed to test the site-selection argument without requiring textual confirmation. If the MSPs were placed only at Predynastic ceremonial centres with Shemsu Hor associations, and not at other Old Kingdom provincial capitals of equal rank, the spatial pattern itself constitutes evidence of intent that does not depend on the presence of texts.

The "absence of evidence" problem in Saharan-derived sequences. A 400-year gap in dated assemblages has recently been documented in the Tichitt sequence of southeastern Mauritania, where no radiocarbon-dated pottery assemblages exist between approximately 1300 and 900 BCE — yet petrographic analysis confirms that the same pottery fabric (Group A paste: local clays with threshing-waste temper) continued unbroken across this interval, and the same cattle-and-goat pastoralist economy persisted throughout (McIntosh, Casanova & Gauthier 2026). The Tichitt case provides a cautionary parallel from a closely related archaeological context: a "silent" interval in the dated record did not represent a rupture in the tradition, and the model proposing phased cultural evolution (Munson 1971; MacDonald 2011) was ultimately vindicated by higher-precision AMS evidence over the competing model of a static, homogeneous culture. Organic residue analysis has further confirmed ruminant dairy processing in Tichitt pottery across all phases, extending the evidence for continuous pastoralist practice through the dating gap. The present paper's argument for a continuous Meskhetyu tradition across the 500-year interval between the Shemsu Hor integration and the Giza culmination is structurally identical: it proposes that the gap reflects archaeological visibility and state capacity, not absence of knowledge. The Tichitt precedent does not prove the Egyptian case, but it demonstrates that this category of argument — phased continuity across a "silent" interval, challenged by a "static" model, testable by higher-precision evidence — is not methodologically novel in African archaeology. It has been proposed before, debated rigorously. In the Tichitt case McIntosh and colleagues present their new dates as bringing the extent of the

chronological gaps into focus rather than as closing them, and the continuity argued across that gap remains an interpretation of the ceramic evidence.

Zawiyet el-Mayitin and Seila. These two MSP sites have weaker Predynastic documentation than the other five. If they are excluded, the remaining five sites — Elephantine, Hierakonpolis, Naqada, Abydos, and Edfu — are all major Predynastic ceremonial centres with documented elite activity, and two (Hierakonpolis and Abydos) have explicit Shemsu Hor textual associations. A clustering of five MSPs at five such sites is unlikely to be random, and the spatial correlation remains significant even without the two weaker sites. Seila is also the site at which the competing reading is strongest: Bárta (2005: 181) notes that the Fayum was divided among at least three local power centres in the Old Kingdom, one of them close to Seila, which gives the monument there an economic rationale independent of any Predynastic ceremonial history. If future survey confirms limited Predynastic ceremonial activity at Zawiyet el-Mayitin and Seila, the transmission model must explain why MSPs were placed there — whether as nodes in a broader territorial program that included non-Shemsu-Hor sites, or because Predynastic activity exists but remains archaeologically undetected. Prediction 6 should be evaluated against the five well-documented sites; the two weaker sites provide an additional test of the model's explanatory scope.

None of these limitations are fatal to the hypothesis. They define where the argument currently rests — on spatial correlation, astronomical orientation, and consilience across independent evidence lines — and where decisive tests would move it from inference to demonstration.

15. Conclusion

The pyramid tradition did not begin with Djoser's Step Pyramid as a royal tomb. It began earlier, at a lower scale, at a specific set of sites — the major Predynastic ceremonial centres of Upper Egypt — with structures that were explicitly not tombs. The seven minor step pyramids of Phase Zero were territorial and cultic markers built at the Shemsu Hor's own integration sites, oriented according to an astronomical tradition consistent with origins in the Saharan pastoralist world. The MSP program was abandoned only when Khufu centralised the entire tradition into a single monument at Giza.

Belmonte's field measurements confirm that el-Kula, the provincial pyramid at Nekhen, is oriented toward Meskhetyu at the precise site where that tradition is archaeologically documented in bone, burial, and ritual sacrifice. The bull on the ground and the bull in the sky are consistent with a shared symbolic inheritance expressed at different scales.

Phase Zero demonstrated what to build. Sneferu demonstrated how to build it at scale. Khufu demonstrated what happens when both streams of knowledge converge under a single centralised state.

The ~500-year gap between the Shemsu Hor integration period and the Giza culmination was not a gap in knowledge or symbolic tradition. It was primarily a gap in state capacity to scale the existing markers into a single cosmological monument.

The workers who drove the first shaft into the bedrock below Giza were not inventing something new. They were continuing a tradition whose symbolic foundations — the circumpolar astronomy of Meskhetyu, the bull cult at HK6, the institutional memory of the Shemsu Hor — are archaeologically documented across a millennium of Upper Egyptian ritual practice and first rendered in monumental stone at el-Kula. Whether that tradition originated with Saharan pastoralist populations, as the transmission hypothesis proposes, remains to be tested by the predictions in Section 12. What Phase Zero is consistent with is that the astronomical and

symbolic foundation was continuous from HK6 to el-Kula. What scaled dramatically under the 4th Dynasty was not the knowledge, but the state capacity to express that foundation at monumental size.

Phase Zero closes the capacity question. The purpose question — what that capacity was ultimately for — continues as the subject of ***The Pyramid as Memory Hypothesis***

References

Primary Textual & Documentary Sources

Allen, J.P. (2015). The Ancient Egyptian Pyramid Texts. 2nd edition. Writings from the Ancient World 38. Atlanta: SBL Press.

Dümichen, J. (1865). Bauurkunde der Tempelanlagen von Dendera: in einem der geheimen Corridore im Innern der Tempelmauer aufgefunden und erläuternd mitgetheilt. Leipzig: J.C. Hinrichs. Digital edition: Universitätsbibliothek Heidelberg.

Otto, E. (1960). *Das ägyptische Mundöffnungsritual* (2 vols.). Ägyptologische Abhandlungen 3. Wiesbaden: Harrassowitz.

Sethe, K. (1906). Urkunden der 18. Dynastie (Urkunden des ägyptischen Altertums IV), pp. 82–87. Leipzig: J.C. Hinrichs. [Tombos Stele of Thutmose I]

Waddell, W.G. (1940). *Manetho.* Loeb Classical Library 350. Cambridge, MA: Harvard University Press.

Mariette, A. (1870–75). Dendérah: description générale du grand temple de cette ville. Paris. Digital edition: Universitätsbibliothek Heidelberg.

Chronology & Historical Synthesis

Ciavatti, A. (2022). Le règne de Snéfrou : nouvel examen des sources chronologiques. Bulletin de l'Institut français d'archéologie orientale 122: 107–153. DOI: 10.4000/bifao.11269.

Dodson, A. and Hilton, D. (2004). The Complete Royal Families of Ancient Egypt. London: Thames & Hudson; Cairo: American University in Cairo Press. [Figure cited as reported by Belmonte and Magli (2015: n. 4); not checked in the original.]

Hornung, E. (2006). The Chronology of Ancient Egypt. In E. Hornung, R. Krauss & D.A. Warburton (eds.), *Ancient Egyptian Chronology*, pp. 1–16. Leiden: Brill. DOI: 10.1163/9789047418239_002.

Hornung, E., Krauss, R. and Warburton, D.A. (eds) (2006). Ancient Egyptian Chronology. Handbook of Oriental Studies 83. Leiden: Brill. [Chronological table, pp. 490–491.]

Petrie, W.M.F. (1924). A History of Egypt, Vol. I. London. [Page 60, as cited by Verner (2001: 373, n. 99).]

Schneider, T. (2002). Lexikon der Pharaonen. Düsseldorf: Albatros. ISBN 3-491-96053-3. [Entry "Cheops", beginning on p. 100; the end page is given as 102 and as 104 in different listings and has not been checked in the book.]

Shaw, I. (ed.) (2000). The Oxford History of Ancient Egypt. Oxford: Oxford University Press.

Takahashi, K. and Nishisaka, A. (2016). Some Notes on the Graffiti Written on the Cover Stones from the Second Boat Pit of Khufu [in Japanese]. Orient (Bulletin of the Society for Near Eastern Studies in Japan) 59(1): 2–13. DOI: 10.5356/jorient.59.1_2.

Verner, M. (2001). Archaeological Remarks on the 4th and 5th Dynasty Chronology. Archiv Orientální 69: 363–418.

von Beckerath, J. (1997). Chronologie des pharaonischen Ägypten: Die Zeitbestimmung der ägyptischen Geschichte von der Vorzeit bis 332 v. Chr. Münchner Ägyptologische Studien 46. Mainz: Philipp von Zabern. [Figures cited as reported by Belmonte and Magli (2015: n. 4).]

Winand, J. (2005). Temps physique et temps culturels. Le cas de l'Égypte ancienne. *Bulletin de la Société Royale des Sciences de Liège* 74(4): 311–325.

Predynastic & Early Dynastic Egypt

Baines, J. (1995). Kingship, Definition of Culture, and Legitimation. In D. O'Connor & D.P. Silverman (eds.), *Ancient Egyptian Kingship*, pp. 3–47. Leiden: Brill.

Baines, J. and Málek, J. (2000). Cultural Atlas of Ancient Egypt. Rev. ed. New York: Checkmark Books / Facts on File. ISBN: 978-0816040025.

Bussmann, R. (2014). Scaling the State: Egypt in the Third Millennium BC. *Archaeology International* 17: 79–93. DOI: 10.5334/ai.1708.

Bussmann, R. (2023). *The Archaeology of Pharaonic Egypt: Society and Culture, 2700–1700 BC.* Cambridge: Cambridge University Press.

Castillos, J.J. (2009). The Development and Nature of Inequality in Early Egypt. *British Museum Studies in Ancient Egypt and Sudan* 13: 73–81.

Dee, M., Wengrow, D., Shortland, A., Stevenson, A., Brock, F., Girdland Flink, L. and Bronk Ramsey, C. (2013). An absolute chronology for early Egypt using radiocarbon dating and Bayesian statistical modelling. Proceedings of the Royal Society A 469: 20130395. DOI: 10.1098/rspa.2013.0395.

Emery, W.B. (1958). *Excavations at Saqqara: Great Tombs of the First Dynasty III.* Egypt Exploration Society Excavation Memoir 47. Cairo: Government Press; London: Egypt Exploration Society.

Engel, E.-M. (2008). The Royal Tombs at Umm el-Qa'ab. *Archéo-Nil* 18: 30–41. DOI: 10.11588/propylaeumdok.00005195.

Fischer, H.G. (1996). *Egyptian Studies III: Varia Nova.* New York: The Metropolitan Museum of Art.

Frankfort, H. (1978). *Kingship and the Gods: A Study of Ancient Near Eastern Religion as the Integration of Society and Nature.* Chicago: University of Chicago Press. Available at: https://isac.uchicago.edu/sites/default/files/uploads/shared/docs/kingship.pdf

Helck, W. (1974). Die altägyptischen Gaue. Beihefte zum Tübinger Atlas des Vorderen Orients, Reihe B (Geisteswissenschaften), Nr. 5. Wiesbaden: L. Reichert. ISBN: 3-920153-27-8.

Kahl, J. (2001). Hieroglyphic Writing During the Fourth Millennium BC: an Analysis of Systems. *Archéo-Nil* 11: 103–135.

Kahl, J. (2007). Ra is my Lord: Searching for the Rise of the Sun God at the Dawn of Egyptian History. Menes 1. Wiesbaden: Harrassowitz.

Mallory, L.M. (2000). Predynastic and First Dynasty Egyptian Basalt Vessels. PhD thesis, Department of Near and Middle Eastern Civilizations, University of Toronto.

Miniaci, G. (2024). Early Dynastic Votives as Source for Late Middle Kingdom Iconography: An Archaeological Discovery at the Time of the Pharaohs? *Journal of Egyptian Archaeology* 110. DOI: 10.1177/03075133241301086.

Randall-Maciver, D. & Mace, A.C. (1902). *El Amrah and Abydos, 1899–1901.* Egypt Exploration Fund, Special Extra Publication. London.

Weill, R. (1961). Recherches sur la Ire dynastie et les temps prépharaoniques. Bibliothèque d'Étude 38. Cairo: Institut Français d'Archéologie Orientale.

Wengrow, D. (2006). The Archaeology of Early Egypt: Social Transformations in North-East Africa, 10,000 to 2650 BC. Cambridge: Cambridge University Press. DOI: 10.1017/CBO9780511499662.

Wengrow, D., Dee, M., Foster, S., Stevenson, A. and Bronk Ramsey, C. (2014). Cultural convergence in the Neolithic of the Nile Valley: a prehistoric perspective on Egypt's place in Africa. *Antiquity* 88(339): 95–111. DOI: 10.1017/S0003598X00050249.

Wilkinson, T.A.H. (1999). Early Dynastic Egypt. London and New York: Routledge. ISBN: 0-415-18633-1.

Hierakonpolis & HK6 Excavations

Adams, B. (1998). Something Very Special down in the Elite Cemetery. In R. Friedman (ed.), *Nekhen News* 10, pp. 3–4.

Bussmann, R. (2011). Local traditions in early Egyptian temples. In R.F. Friedman and P.N. Fiske (eds.), Egypt at its Origins 3. Orientalia Lovaniensia Analecta 205. Leuven: Peeters, pp. 747–762.

Case, H. and Crowfoot Payne, J. (1962). Tomb 100: The Decorated Tomb at Hierakonpolis. *Journal of Egyptian Archaeology* 48: 5–18.

Crowfoot Payne, J. (1973). Tomb 100: The Decorated Tomb at Hierakonpolis Confirmed. Journal of Egyptian Archaeology 59: 31–35.

Droux, X., Friedman, R.F. and Pieri, A. (2024). The elite Predynastic cemetery at Hierakonpolis HK6: 2016–2018 progress report. In Y. Tristant, J. Villaeys and E. Ryan (eds.), *Egypt at its Origins 7.* Orientalia Lovaniensia Analecta 323. Leuven: Peeters, pp. 105–152.

Fahmy, A.G., Friedman, R. and Fadl, M. (2008). *Balanites aegyptiaca* offerings in Predynastic elite graves at Hierakonpolis. *Nekhen News* 20: 24–25.

Friedman, R. (ed.) (1998). *Nekhen News* 10 (Special Centenary Edition). Hierakonpolis Expedition.

Friedman, R.F. (2009). Hierakonpolis Locality HK29A: The Predynastic Ceremonial Center Revisited. *Journal of the American Research Center in Egypt* 45: 79–104.

Friedman, R.F., Van Neer, W. and Linseele, V. (2011). The elite Predynastic cemetery at Hierakonpolis: 2009–2010 update. In R.F. Friedman and P.N. Fiske (eds.), *Egypt at its Origins 3.* Orientalia Lovaniensia Analecta 205. Leuven: Peeters, pp. 157–191.

Huyge, D. (2014). The Painted Tomb, Rock Art and the Recycling of Predynastic Egyptian Imagery. *Archéo-Nil* 24: 93–102.

Kemp, B.J. (2018). Ancient Egypt: Anatomy of a Civilization. 3rd edition. Abingdon and New York: Routledge. ISBN 978-0-415-82726-3.

Marinova, E., Ryan, P., Van Neer, W. and Friedman, R. (2013). Animal dung from arid environments and archaeobotanical methodologies for its analysis: An example from animal burials of the Predynastic elite cemetery HK6 at Hierakonpolis, Egypt. *Environmental Archaeology* 18(1): 58–71. DOI: 10.1179/1461410313Z.00000000020.

McNamara, L. (2008). The revetted mound at Hierakonpolis and early kingship: a re-interpretation. In B. Midant-Reynes and Y. Tristant (eds.), Egypt at its Origins 2. Orientalia Lovaniensia Analecta 172. Leuven: Peeters, 901–936.

Meyrat, P. (2017). Defeating the Wild Bull: Achievements of the King at Nekhen. *Nekhen News* 29: 27.

Meyrat, P. (2021). The Bull of Nekhen. Investigating the Origins of the Apis Cult. In E.C. Köhler, N. Kuch, F. Junge and A.-K. Jeske (eds.), *Egypt at its Origins 6.* Orientalia Lovaniensia Analecta 303. Leuven: Peeters, pp. 559–575.

Quibell, J.E. and Green, F.W. (1900). *Hierakonpolis, Part I.* Egyptian Research Account, Fourth Memoir. London: Bernard Quaritch.

Quibell, J.E. and Green, F.W. (1902). *Hierakonpolis. Part II.* London: Bernard Quaritch.

3rd Dynasty: Historical & Prosopographical Studies

Baud, M. (2002). *Djéser et la IIIe dynastie.* Paris: Pygmalion.

Helck, W. (1980). Imhotep. In W. Helck and W. Westendorf (eds.), *Lexikon der Ägyptologie*, Vol. III, cols. 145–148. Wiesbaden: Harrassowitz.

Step Pyramid: Excavations & Architecture

Arnold, D. (2003). *The Encyclopaedia of Ancient Egyptian Architecture.* Princeton: Princeton University Press.

Dodson, A. and Ikram, S. (2008). *The Tomb in Ancient Egypt.* London: Thames & Hudson.

Firth, C.M., Quibell, J.E. and Lauer, J.-P. (1935). *The Step Pyramid.* 2 vols. Cairo: Institut Français d'Archéologie Orientale.

Lauer, J.-P. (1936). *La pyramide à degrés: l'architecture.* 2 vols. Cairo: Institut Français d'Archéologie Orientale.

Lauer, J.-P. (1960). Observations sur les pyramides. Bibliothèque d’étude 30. Cairo: Imprimerie de l’Institut français d’archéologie orientale.

Lauer, J.-P. (1962). *Histoire monumentale des pyramides d'Égypte, Vol. I: Les pyramides à degrés.* Cairo: Institut Français d'Archéologie Orientale.

Wilkinson, R.H. (2000). *The Complete Temples of Ancient Egypt.* London: Thames & Hudson.

Minor Step Pyramids: Excavation & Attribution

Bárta, M. (2005). Location of the Old Kingdom pyramids in Egypt. Cambridge Archaeological Journal 15(2): 177–191. DOI: 10.1017/S0959774305000090.

Ćwiek, A. (1998). Date and Function of the so-called Minor Step Pyramids. *Göttinger Miszellen* 162: 39–52.

Dreyer, G. and Kaiser, W. (1980). Zu den kleinen Stufenpyramiden Ober- und Mittelägyptens. *Mitteilungen des Deutschen Archäologischen Instituts, Abteilung Kairo* 36: 43–59, plates 68–77.

Dreyer, G. and Swelim, N. (1982). Die kleine Stufenpyramide von Abydos-Süd (Sinki). Mitteilungen des Deutschen Archäologischen Instituts Abteilung Kairo 38: 83–93, pls 11–14.

Maragioglio, V. & Rinaldi, C.A. (1963). *L'architettura delle Piramidi Menfite, Parte II: La Piramide di Sechemkhet, la Layer Pyramid di Zauiet el-Aryan e le minori piramidi attribuite alla III dinastia.* Rapallo: Tipografia Canessa.

Marouard, G. (2014). Excavation report: Edfu South Pyramid. Oriental Institute, University of Chicago. Available at: https://isac.uchicago.edu/sites/default/files/uploads/shared/docs/ar/11-20/14-15/ar2015-Edfu.pdf

Marouard, G. and Papazian, H. (2012). The Edfu Pyramid Project. Oriental Institute News & Notes 213: 3–9.

Radwan, A. (2003). The step pyramids. In Z. Hawass (ed.), The Treasures of the Pyramids. Cairo: American University in Cairo Press, pp. 86–111. [Cited via Bárta (2005: 181) for the heights of the minor step pyramids; not independently consulted.]

Pyramid Construction & Engineering

Abou Zeid, S.M., Fekri, M.M. & Qandil, H.A. (2021). The Phyles System in Ancient Egypt. *Journal of the Faculty of Tourism and Hotels — University of Sadat City* 5(2): 210–219. DOI: 10.21608/mfth.2021.281765.

Arnold, D. (1991). Building in Egypt: Pharaonic Stone Masonry. New York: Oxford University Press.

Brichieri-Colombi, S. (2019). The Ramp at Hatnub Quarry: No Solution for Pyramids. PalArch's Journal of Archaeology of Egypt/Egyptology 16(1): 1–21.

Creasman, P.P. and Doyle, N. (2010). Overland Boat Transportation During the Pharaonic Period. *Journal of Ancient Egyptian Interconnections* 2(3): 14–30.

Dash, G. (2015). The Great Pyramid's Footprint: Results from Our 2015 Survey. AERAGRAM 16(2): 8–12, 14. [Glen Dash Foundation Survey of 2015, carried out with Ancient Egypt Research Associates. Reports the mean casing base as 230.363 m and, on Petrie's cubit of 20.62 inches, an average side length between 440.05 and 439.62 cubits; the mean deviation of the casing from the cardinal directions is −3′ 54″ ± 44″.]

Gillings, R.J. (1972). *Mathematics in the Time of the Pharaohs.* Cambridge, MA: MIT Press.

Gourdon, Y. (2017). Les inscriptions rupestres de Hatnoub. In Rapport d'activité 2015–2016, Supplément au Bulletin de l'Institut français d'archéologie orientale 116: 238–250.

Haase, M. (2004). Eine Stätte für die Ewigkeit: Der Pyramidenkomplex des Cheops aus baulicher, architektonischer und kulturhistorischer Sicht. Zaberns Bildbände zur Archäologie. Mainz am Rhein: Philipp von Zabern. 147 pp. ISBN 3-8053-3105-3.

Hawass, Z. and Lehner, M. (1997). Builders of the Pyramids. *Archaeology* 50(1): 30–38.

Klemm, D.D. and Klemm, R. (2010). *The Stones of the Pyramids: Provenance of the Building Stones of the Old Kingdom Pyramids of Egypt.* Berlin/New York: De Gruyter. DOI: 10.1515/9783110214519.

Lauer, J.-P. (1976). À propos du prétendu désastre de la pyramide de Meïdoum. Chronique d'Égypte 51: 72–89.

Lehner, M. (1983). Some observations on the layout of the Khufu and Khafre pyramids. Journal of the American Research Center in Egypt 20: 7–25.

Lehner, M. (1997). *The Complete Pyramids.* London: Thames & Hudson.

Lehner, M. (2015). Labor and the Pyramids: The Heit el-Ghurab "Workers Town" at Giza. In P. Steinkeller and M. Hudson (eds.), Labor in the Ancient World. International Scholars Conference on Ancient Near Eastern Economies 5. Dresden: ISLET-Verlag, pp. 397–522.

Miatello, L. (2010). Examining the Grand Gallery in the Pyramid of Khufu and its Features. PalArch's Journal of Archaeology of Egypt/Egyptology 7(6): 1–36.

Monnier, F. and Puchkov, A. (2016). The construction phases of the Bent Pyramid at Dahshur. A reassessment. Égypte Nilotique et Méditerranéenne 9: 15–36.

Morishima, K., Kuno, M., Nishio, A. et al. (2017). Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons. Nature 552: 386–390. DOI: 10.1038/nature24647. [Reports a void with a cross section comparable to the Grand Gallery and a length of at least 30 m, located above the Grand Gallery on the evidence of three independent detector technologies. Consulted in the authors' pre-submission manuscript, arXiv:1711.01576v2.]

Nuzzolo, M. (2015). The Bent Pyramid of Snefru at Dahshur. A project failure or an intentional architectural framework? Studien zur Altägyptischen Kultur 44: 259–282.

Petrie, W.M.F. (1883). *The Pyramids and Temples of Gizeh.* London: Field & Tuer.

Procureur, S., Morishima, K., Kuno, M. et al. (2023). Precise characterization of a corridor-shaped structure in Khufu's Pyramid by observation of cosmic-ray muons. Nature Communications 14: 1144. DOI: 10.1038/s41467-023-36351-0. Open access. [Gives the corridor behind the North Face chevrons as about 9 m long with a transverse section of about 2.0 by 2.0 m; the detailed fit returns L = 9.06 ± 0.05 m, W = 2.02 ± 0.05 m and H = 2.18 ± 0.04 m. Consulted directly for this paper.]

Romer, J. (2007). The Great Pyramid: Ancient Egypt Revisited. Cambridge: Cambridge University Press. ISBN: 978-0521871662.

Roth, A.M. (1991). Egyptian Phyles in the Old Kingdom: The Evolution of a System of Social Organization. Studies in Ancient Oriental Civilization 48. Chicago: The Oriental Institute.

Scheuring, S.A. (2025). Construction of the Great Pyramid with pulley-like systems using counter-weights on sliding-ramps. *npj Heritage Science* 13: 473. DOI: 10.1038/s40494-025-02018-w.

Stocks, D.A. (2001). Testing ancient Egyptian granite-working methods in Aswan, Upper Egypt. *Antiquity* 75(287): 89–94. DOI: 10.1017/S0003598X00052388.

Tallet, P. (2017). Les papyrus de la mer Rouge I: Le « journal de Merer » (Papyrus Jarf A et B). Mémoires publiés par les membres de l'Institut français d'archéologie orientale 136. Cairo: IFAO.

Tallet, P. and Marouard, G. (2014). The Harbor of Khufu on the Red Sea Coast at Wadi al-Jarf, Egypt. *Near Eastern Archaeology* 77(1): 4–14. DOI: 10.5615/neareastarch.77.1.0004.

Tallet, P. and Marouard, G. (2016). The Harbor Facilities of King Khufu on the Red Sea Shore: The Wadi al-Jarf/Tell Ras Budran System. Journal of the American Research Center in Egypt 52: 135–177. DOI: 10.5913/jarce.52.2016.a009.

Wong, J.Y. (2021). The Role of Environmental Factors in the Early Development of Egyptian Stone Architecture. *Cambridge Archaeological Journal* 31(1): 53–65. DOI: 10.1017/S0959774320000232.

Zapassky, E., Gadot, Y., Finkelstein, I. and Benenson, I. (2012). An Ancient Relation between Units of Length and Volume Based on a Sphere. PLOS ONE 7(3): e33895. DOI: 10.1371/journal.pone.0033895.

Archaeoastronomy & Astronomical Orientations

Alcouffe, A., Duchesne, S., Tupikova, I., Buchez, N., Gérard, P., Mathieu, B., Labba, C., Hochstrasser-Petit, C., Nominé, A., Ludes, B., Ribéron, A., Boyer, A., Midant-Reynes, B. and Crubézy, E. (2025). From Stars to State: Astral Patterns and the Rise of Pharaonic Egypt at Adaïma (Upper Egypt). *Journal of Archaeological Method and Theory* 32, Article 53. DOI: 10.1007/s10816-025-09724-6.

Ali, M., Fekri, M. and EL Mahdy, I. (2021). The Astronomical Orientation of the Seven Minor Step Pyramids. *Journal of the Faculty of Tourism and Hotels — University of Sadat City* 5(1): 71 –87. DOI: 10.21608/mfth.2021.180278.

Badawy, A. (1964). The stellar destiny of pharaoh and the so-called air-shafts of Cheops's pyramid. Mitteilungen des Instituts für Orientforschung 10(2/3): 189–206.

Belmonte, J.A. (2001). On the Orientation of Old Kingdom Egyptian Pyramids. Journal for the History of Astronomy, Supplement 32 (Archaeoastronomy 26): S1–S20. DOI: 10.1177/002182860103200202.

Belmonte, J.A., Esteban, C., Perera Betancort, M.A. and Marrero, R. (2002). Archaeoastronomy in the Sahara: The Tombs of the Garamantes at Wadi El Agial, Fezzan, Libya. *Journal for the History of Astronomy* 33: S1–S19. DOI: 10.1177/002182860203300102.

Belmonte, J.A. & Lull, J. (2023). *Astronomy of Ancient Egypt: A Cultural Perspective.* Cham: Springer. ISBN 9783031118289.

Belmonte, J.A. and Magli, G. (2015). Astronomy, architecture and symbolism: the global project of Sneferu at Dahshur. *Journal for the History of Astronomy* 46: 173–205. DOI: 10.1177/0021828614566500.

Belmonte, J.A., Shaltout, M. and Fekri, M. (2005). Astronomy and landscape in ancient Egypt: challenging the enigma of the minor step pyramids. *Trabajos de Egiptologia: Papers on Ancient Egypt* 4: 7–18.

Belmonte, J.A., Shaltout, M. and Fekri, M. (2008). On the Orientation of Ancient Egyptian Temples: (4) Epilogue in Serabit el Khadim and Overview. Journal for the History of Astronomy 39(2): 181–211.

Dorner, J. (1981). Die Absteckung und astronomische Orientierung ägyptischer Pyramiden. Unpublished PhD dissertation, Innsbruck.

Doyle, L.R. and Wilcox, T.J. (1986). Statistical Analysis of Namoratunga: An Archaeoastronomical Site in Sub-Saharan Africa? *Azania: Archaeological Research in Africa* 21(1): 125–129. DOI: 10.1080/00672708609511373.

Edwards, I.E.S. (1981). The Air-Channels of Chephren's Pyramid. In *Studies in Ancient Egypt, the Aegean, and the Sudan: Essays in Honor of Dows Dunham on the Occasion of his 90th Birthday, June 1, 1980*, pp. 55–57. Boston: Museum of Fine Arts.

Haynie, D.T. (2015). A Great Comet and Ceremonial Site Development at Nabta Playa. *Mediterranean Archaeology & Archaeometry* 15(1): 127–134.

Locher, K. (1985). Probable Identification of the Ancient Egyptian Circumpolar Constellations. *Archaeoastronomy* 8 (Supplement to *Journal for the History of Astronomy* 16): S152–S155. DOI: 10.1177/002182868501600907.

Lull, J. (2008). Meschetiu in der Mythologie und der Orientierung der ägyptischen Tempel. Acta Praehistorica et Archaeologica 40: 85–92.

Lull, J. and Belmonte, J.A. (2006). A firmament above Thebes: uncovering the constellations of ancient Egyptians. *Journal for the History of Astronomy* 37: 373–392. DOI: 10.1177/002182860603700401.

Lynch, B.M. and Robbins, L.H. (1978). Namoratunga: The First Archeoastronomical Evidence in Sub-Saharan Africa. *Science* 200(4343): 766–768. DOI: 10.1126/science.200.4343.766.

Magli, G. (2018). Architecture, Astronomy and Sacred Landscape in Ancient Egypt. Cambridge: Cambridge University Press.

Malville, J.M., Schild, R., Wendorf, F. and Brenmer, R. (2008). Astronomy of Nabta Playa. In *African Cultural Astronomy*, pp. 131–143. Springer. DOI: 10.1007/978-0-387-47333-8_9.

Nell, E. and Ruggles, C. (2014). The orientations of the Giza pyramids and associated structures. *Journal for the History of Astronomy* 45: 304–360.

Nemes, G.W. (2020). The mythological importance of the constellation Msḫtjw in mortuary representations until the end of the New Kingdom. Égypte Nilotique et Méditerranéenne (ENiM) 13: 1–61. Open access: enim-egyptologie.fr. [Locates the adze–asterism determinative identity in Pyramid Texts Spell 302 and Coffin Texts Spell 61, crediting Wallin 2002; cited in Section 11 for Link 3.]

Pólak, B. (1952). Astronomická orientace egyptských chrámů a pyramid. Říše hvězd 33. [Cited via Lull (2008) for the Megrez–Phecda proposal; not independently consulted.]

Priskin, G. (2019). The Constellations of the Egyptian Astronomical Diagrams. Égypte Nilotique et Méditerranéenne 12: 137–180.

Rawlins, D. and Pickering, K. (2001). Astronomical orientation of the pyramids. Nature 412: 699, with reply by K. Spence.

Rodríguez-Antón, A., Urrutia-Aparicio, M., González García, A.C. and Belmonte, J.A. (2023). Archaeoastronomy and Conflict: On the Orientation of Prehistoric Funerary Monuments in Western Sahara. Sustainability 15(3): 2005. DOI: 10.3390/su15032005.

Shaltout, M., Belmonte, J.A. and Fekri, M. (2007). On the Orientation of Ancient Egyptian Temples: (3) Key Points at Lower Egypt and Siwa Oasis, Part II. Journal for the History of Astronomy 38(4): 413–442.

Soper, R. (1982). Archaeo-astronomical Cushites: some comments (with comments by B.M. Lynch). Azania 17: 145–162.

Spence, K. (2000). Ancient Egyptian chronology and the astronomical orientation of pyramids. *Nature* 408: 320–324. DOI: 10.1038/35042510.

Szwec, M. (2022). Tracking the Culmination of the Celestial Cow Motif into Royal Spheres: An Examination of Celestial Phenology and Cattle Pastoralism in Early Ideologies of Power. Birmingham Egyptology Journal 9: 85–111.

Trimble, V. (1964). Astronomical investigation concerning the so-called air-shafts of Cheops's pyramid. Mitteilungen des Instituts für Orientforschung 10(2/3): 183–187.

Vondrák, J., Capitaine, N. & Wallace, P. (2011). New precession expressions, valid for long time intervals. Astronomy & Astrophysics 534: A22. DOI: 10.1051/0004-6361/201117274.

Wallin, P. (2002). Celestial Cycles: Astronomical Concepts of Regeneration in the Ancient Egyptian Coffin Texts. Uppsala Studies in Egyptology 1. Uppsala: Uppsala University. [Cited via Nemes 2020 for the determinative identity; not independently consulted.]

Egyptian Religion, Iconography & Deification

Almansa-Villatoro, M.V. (2019). The Cultural Indexicality of the N41 Sign for *bj3*: The Metal of the Sky and the Sky of Metal. *Journal of Egyptian Archaeology* 105(1): 73–81. DOI: 10.1177/0307513319899948.

Dodson, A. (2012). Hetepheres I. In R.S. Bagnall, K. Brodersen, C.B. Champion, A. Erskine and S.R. Huebner (eds.), *The Encyclopedia of Ancient History.* Oxford: Wiley-Blackwell. DOI: 10.1002/9781444338386.wbeah15196.

Edwards, S. (1995). The Symbolism of the Eye of Horus in the Pyramid Texts. PhD thesis, University College of Swansea.

Gardiner, A.H. (1938). The House of Life. *Journal of Egyptian Archaeology* 24(1): 157–179.

Hassan, F.A. (1992). Primeval goddess to divine king: the mythology behind Egyptian civilization. In R. Friedman and B. Adams (eds.), *The Followers of Horus: Studies dedicated to Michael Allen Hoffman*, pp. 307–321. Oxford: Oxbow Press.

Krauss, R. (1997). *Astronomische Konzepte und Jenseitsvorstellungen in den Pyramidentexten.* Ägyptologische Abhandlungen 59. Wiesbaden: Harrassowitz.

Omran, W. (2014). The Egyptian and the Hellenistic Characteristics of the Asklepieion. Journal of Faculty of Tourism and Hotels, Fayoum University 8(2): 69–112.

Roth, A.M. (1992). The Psš-kf and the Opening of the Mouth Ceremony: A Ritual of Birth and Rebirth. *Journal of Egyptian Archaeology* 78: 113–147.

Roth, A.M. (1993). Fingers, Stars, and the Opening of the Mouth: The Nature and Function of the nṯrwj-Blades. *Journal of Egyptian Archaeology* 79: 57–79.

Sethe, K. (1902). *Imhotep, der Asklepios der Ägypter.* Untersuchungen zur Geschichte und Altertumskunde Ägyptens 2(4). Leipzig.

Sherkova, T.A. (2023). Eye Painting Ritual, Bull Sacrifice and the Myth of the Eye of Horus in Ancient Egypt [in Russian]. Bulletin of Science and Practice 9(4): 535–558. DOI: 10.33619/2414-2948/89/71.

Teeter, E. (2011). *Religion and Ritual in Ancient Egypt.* Cambridge: Cambridge University Press.

Wildung, D. (1977). *Imhotep und Amenhotep: Gottwerdung im alten Ägypten.* Munich: Deutscher Kunstverlag.

Wilkinson, R.H. (2003). *The Complete Gods and Goddesses of Ancient Egypt.* London: Thames & Hudson.

Bioarchaeology, Isotopes & Population Genetics

Derry, D.E. (1956). The Dynastic Race in Egypt. *Journal of Egyptian Archaeology* 42: 80–85.

Dominy, N.J., Ikram, S., Moritz, G.L., Wheatley, P.V., Christensen, J.N., Chipman, J.W. and Koch, P.L. (2020). Mummified baboons reveal the far reach of early Egyptian mariners. eLife 9: e60860.

Lipson, M., Ringbauer, H., Lucarini, G. et al. (2025). High continuity of forager ancestry in the Neolithic period of the eastern Maghreb. *Nature* 641: 925–931. DOI: 10.1038/s41586-025-08699-4.

Morez Jacobs, A., Irish, J.D., Cooke, A. et al. (2025). Whole-genome ancestry of an Old Kingdom Egyptian. *Nature* 644: 714–721. DOI: 10.1038/s41586-025-09195-5.

Salem, N. et al. (2025). Ancient DNA from the Green Sahara reveals ancestral North African lineage. *Nature* 641: 144–150. DOI: 10.1038/s41586-025-08793-7.

Simonetti, A., Buzon, M.R., Smith, S.T. and Schrader, S.A. (2023). Assessing the impact of Holocene climate change on bioavailable strontium within the Nile River Valley: geochemical and radiogenic isotope perspectives. Bioarchaeology International 7: 211–233.

Spies, M.J., Alblas, A., Ambrose, S.H., Barakat, S., Barberena, R., Bataille, C., et al. (2025). Strontium isoscapes for provenance, mobility and migration: the way forward. *Royal Society Open Science* 12(6): 250283. DOI: 10.1098/rsos.250283.

van de Loosdrecht, M. et al. (2018). Pleistocene North African genomes link Near Eastern and sub-Saharan African human populations. *Science* 360(6388): 548–552.

Zakrzewski, S.R. (2007). Population continuity or population change: Formation of the ancient Egyptian state. *American Journal of Physical Anthropology* 132(4): 501–509. DOI: 10.1002/ajpa.20569.

Zooarchaeology & Pastoralism

Van Neer, W., De Cupere, B. and Friedman, R. (2024). The earliest evidence for deformation of livestock horns: The case of Predynastic sheep from Hierakonpolis, Egypt. *Journal of Archaeological Science* 172: 106104. DOI: 10.1016/j.jas.2024.106104.

Van Neer, W., De Cupere, B. and Friedman, R.F. (2026). New archaeozoological analysis of baboons buried at Hierakonpolis (Upper Egypt) shows two species were imported in the Predynastic period. *Archaeological and Anthropological Sciences* 18(3): 62. DOI: 10.1007/s12520-026-02416-6.

Van Neer, W. and Linseele, V. (2003). A second elephant at HK6. Nekhen News 15: 11–12.

Geoarchaeology & Environmental Studies

Ghoneim, E., Ralph, T.J., Onstine, S. et al. (2024). The Egyptian pyramid chain was built along the now abandoned Ahramat Nile Branch. *Communications Earth and Environment* 5: 233. DOI: 10.1038/s43247-024-01379-7.

Hassan, F. (2007). Droughts, Famine and the Collapse of the Old Kingdom: Re-reading Ipuwer. In Z. Hawass and J. Richards (eds.), *The Archaeology and Art of Ancient Egypt: Essays in Honor of David B. O'Connor*, pp. 357–377. Cairo: Supreme Council of Antiquities.

Hoffman, M.A., Hamroush, H.A. and Allen, R.O. (1987). The environment and evolution of an early Egyptian urban center: archaeological and geochemical investigations at Hierakonpolis. *Geoarchaeology* 2(1): 1–13. DOI: 10.1002/gea.3340020102.

Matton, G. & Jébrak, M. (2014). The "eye of Africa" (Richat dome, Mauritania): An isolated Cretaceous alkaline-hydrothermal complex. Journal of African Earth Sciences, 97, 109–124. https://doi.org/10.1016/j.jafrearsci.2014.04.006

Taylor, C.D. & Giles, S.A. (2015). Mineral potential for incompatible element deposits hosted in pegmatites, alkaline rocks, and carbonatites in the Islamic Republic of Mauritania (phase V, deliverable 87). In Second Projet de Renforcement Institutionnel du Secteur Minier de la République Islamique de Mauritanie (PRISM-II). U.S. Geological Survey Open-File Report 2013-1280-Q, 41 p. https://doi.org/10.3133/ofr20131280Q

Trzciński, J., Kuraszkiewicz, K.O. and Welc, F. (2010). Preliminary report on geoarchaeological research in West Saqqara. *Polish Archaeology in the Mediterranean* 19: 194–208.

Welc, F. (2011). The Third Dynasty open quarry west of the Netjerykhet pyramid complex (Saqqara). *Études et Travaux* 24: 271–304.

Saharan Archaeology & Rock Art

Bárta, M. (2014). Prehistoric Mind in Context: An Essay on Possible Roots of Ancient Egyptian Civilisation. In *Paradigm Found: Archaeological Theory — Present, Past and Future*, pp. 188–201. Oxford: Oxbow Books.

di Lernia, S. (2006). Building monuments, creating identity: Cattle cult as a social response to rapid environmental changes in the Holocene Sahara. *Quaternary International* 151: 50–62. DOI: 10.1016/j.quaint.2006.01.014.

di Lernia, S. and Gallinaro, M. (2010). The date and context of Neolithic rock art in the Sahara: engravings and ceremonial monuments from Messak Settafet (south-west Libya). Antiquity 84(326): 954–975. DOI: 10.1017/S0003598X00067016.

di Lernia, S., Tafuri, M.A., Gallinaro, M., Alhaique, F., Balasse, M., Cavorsi, L., Fullagar, P.D., Mercuri, A.M., Monaco, A., Perego, A. and Zerboni, A. (2013). Inside the “African Cattle Complex”: Animal Burials in the Holocene Central Sahara. PLoS ONE 8(2): e56879. DOI: 10.1371/journal.pone.0056879.

Gauthier, Y. and Gauthier, C. (2004). Un exemple de relation monuments – art rupestre : monuments en corbeilles et grands cercles de pierres du Messak (Libye). *Les Cahiers de l'AARS* 9: 45–62. [Association bulletin, not peer-reviewed. Orientation data for the Messak monuments also appear in Gauthier, Y. and Gauthier, C. (2000), Orientation et distribution de divers types de monuments lithiques du Messak et des régions voisines (Fezzân, Libye), Sahara 11: 87–108.]

Hendrickx, S., Riemer, H., Förster, F. and Darnell, J.C. (2009). Late Predynastic–Early Dynastic rock art scenes of Barbary sheep hunting from Egypt's Western Desert. In H. Riemer, F. Förster, M. Herb and N. Pöllath (eds.), Desert Animals in the Eastern Sahara. Colloquium Africanum 4. Cologne: Heinrich-Barth-Institut, 189–244.

Kuper, R. and Förster, F. (2003). Khufu’s ‘mefat’ expeditions into the Libyan Desert. Egyptian Archaeology 23: 25–28.

Kuper, R. and Kröpelin, S. (2006). Climate-Controlled Holocene Occupation in the Sahara: Motor of Africa’s Evolution. Science 313(5788): 803–807. DOI: 10.1126/science.1130989.

Le Quellec, J.-L. (2011). Figurations rupestres du Sahara et de l'Égypte ancienne. *Archéo-Nil* 21: 125–162.

Paris, F. (2000). African livestock remains from Saharan mortuary contexts. In R.M. Blench and K.C. MacDonald (eds.), The Origins and Development of African Livestock: Archaeology, Genetics, Linguistics and Ethnography. London: UCL Press, pp. 111–126.

Riemer, H. (2013). Dating the paintings of Wadi Sura. In R. Kuper (ed.), Wadi Sura – The Cave of Beasts: A rock art site in the Gilf Kebir (SW Egypt). Africa Praehistorica 26. Cologne: Heinrich-Barth-Institut pp. 38–41.

Schild, R. (ed.) with Czekaj-Zastawny, A. and Królik, H. (2025). *The Megaliths of Nabta Playa.* Warsaw: Institute of Archaeology and Ethnology, Polish Academy of Sciences. Available at: https://rcin.org.pl/Content/247676/The%20Megaliths%20of%20Nabta%20Playa_I.pdf

van Albada, A. and van Albada, A.-M. (2000). La montagne des hommes-chiens: art rupestre du Messak libyen. Paris: Seuil.

Sub-Saharan African Archaeology & Diaspora

Barker, G. and Goucher, C. (eds.) (2015). *The Cambridge World History: Volume 2, A World with Agriculture, 12,000 BCE–500 CE.* Cambridge University Press. DOI: 10.1017/CHO9781139608757.

Caldwell, D. (2013). Western Saharan sculptural families and the possible origins of the Osiris-Horus cycle. *Rock Art Research* 30(2): 174–196.

Cooper, J., Bourgeois, M., Crépy, M. and Gatto, M.C. (2026). Atbai Enclosure Burials: Monumentalism, Pastoralism and Environmental Change in the Mid-Holocene East Nubian Deserts. *African Archaeological Review.* DOI: 10.1007/s10437-026-09654-y.

Gatto, M.C., Mattingly, D.J., Ray, N. and Sterry, M. (eds.) (2019). *Burials, Migration and Identity in the Ancient Sahara and Beyond.* Trans-Saharan Archaeology, Volume 2. Cambridge: Cambridge University Press. DOI: 10.1017/9781108655348.

Hildebrand, E.A., Grillo, K.M., Sawchuk, E.A., et al. (2018). A monumental cemetery built by eastern Africa's first herders near Lake Turkana, Kenya. *Proceedings of the National Academy of Sciences* 115(36): 8942–8947. DOI: 10.1073/pnas.1721975115.

MacDonald, K.C. (2011). Betwixt Tichitt and the IND: the pottery of the Faïta Facies, Tichitt Tradition. *Azania: Archaeological Research in Africa* 46(1): 49–69. DOI: 10.1080/0067270X.2011.553485.

Mattingly, D.J., Sterry, M. and Ray, N. (2019). Dying to be Garamantian: Burial, migration and Garamantian identity. In Gatto et al. (2019), pp. 53–107. DOI: 10.1017/9781108655348.

McIntosh, S.K., Casanova, E. and Gauthier, C. (2026). Revisiting Tichitt: new dates and data from the 1968 excavations by Patrick Munson. *Azania: Archaeological Research in Africa.* DOI: 10.1080/0067270X.2026.2630538.

Munson, P.J. (1971). The Tichitt Tradition: A Late Prehistoric Occupation of the Southwestern Sahara. Ph.D. Dissertation, University of Illinois at Urbana-Champaign. Available at: http://hdl.handle.net/2142/64290.

Sterry, M. and Mattingly, D.J. (2020). *Urbanisation and State Formation in the Ancient Sahara and Beyond.* Cambridge University Press. DOI: 10.1017/9781108637979.

Zep Tepi Series — Companion Papers

Levy, S. (2026a). *The Eye of the Sahara Hypothesis.* Zep Tepi Series, Paper I. Zenodo. DOI: 10.5281/zenodo.18472416.

Levy, S. (2026b). *Zep Tepi: People of the First Time.* Zep Tepi Series, Paper II. Zenodo. DOI: 10.5281/zenodo.19046277.

Levy, S. (2026c). *The Shemsu Hor Hypothesis.* Zep Tepi Series, Paper III. Zenodo. DOI: 10.5281/zenodo.19449606.

Non-Peer-Reviewed Sources

AERA (Ancient Egypt Research Associates) (n.d.). Khufu’s 30-Year Jubilee: Newly Discovered Pieces of a Puzzle. AERAGRAM; online at https://aeraweb.org/khufus-30-year-jubilee/. [Newsletter summary, cited only for its reading of the 14th-count graffito as Khufu’s last count; the graffito itself is published in Takahashi and Nishisaka (2016).]

Choi, H. (2022). *Trapezoidal Step Pyramid Hypothesis (Cannibal Construction / Build-by-Unbuilding).* Unpublished informal model. Documentation available at https://facebook.com/HuniChoiPyramid. Cited for the overbuild-and-carve concept only; the 8 million ton and 14 million ton figures are the author's unpublished estimates and have not been independently verified.

Enmarch, R. and Gourdon, Y. (2018). Ancient quarry ramp system discovered at Hatnub, dated to reign of Khufu. University of Liverpool / Institut français d'archéologie orientale. Press release, November 2018. Available at: https://www.liverpool.ac.uk/archaeology-classics-and-egyptology/news/stories/title,982860,en.php [Press release only; cited solely to record that the force-multiplier interpretation of the Hatnub system has not appeared as a peer-reviewed

excavation report. The Khufu-period dating of the site rests on Gourdon (2017); for a peer-reviewed critique see Brichieri-Colombi (2019).]

History for Granite [pseud.] (2024). *First View of this Pyramid Construction Technique.* Unpublished independent analysis. YouTube video. Available at: https://www.youtube.com/watch?v=q4Vv1aAgVGw. Cited for the Khafre casing stone survey data only; the bonding stone pattern analysis is the presenter's independent observation and has not been published in peer-reviewed form.

Lee, D. (2026). *This New Pyramid Theory Explains the Missing Evidence Cannibalizing Structures.* YouTube, @DamiLeeArch. Available at: https://www.youtube.com/watch?v=h5kWDOuY2Uo.

Artificial Intelligence Use Disclosure

AI language models were used during the development process in a supporting capacity:

- **Claude (Anthropic)** — Primary research partner. Used for full fact-handling, source verification, analysis, and complete document generation, and for the improvement and finalisation of the construction timeline and mechanical advantage calculations.
- **DeepSeek V3** — Literature gathering, smaller calculations, and document patching.
- **Grok (xAI)** — Larger mathematical calculations and adversarial peer review, including the initial construction timeline simulation and mechanical advantage verification.
- **Gemini (Google)** — Supplementary information gathering.
- **Microsoft Copilot** — Image creation.
- **MiniMax (MiniMax M2.7)** — Literature gathering and peer review.

No AI generated the underlying argument, sourced original evidence, or authored interpretive claims. The evidence on which the argument rests derives from published, peer-reviewed sources; the small number of non-peer-reviewed items cited are listed separately under their own heading above and are identified as such at each point of use. The analytical framework, editorial judgments, and conclusions are the author's own.